EVS27
Barcelona, Spain, November 17-20, 2013

49,999 Electric car journeys and counting

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Abstract

The North East of England has been one of the most advanced regions for the demonstration of electric vehicles. So far, over 1100 charging points have been installed in the region through the Government funded Plugged in Places scheme and more than 49,999 electric vehicle journeys have been recorded since 2010 through the Switch EV trial. This paper gives an overview of the findings from this trial.

Keywords: electric vehicles, charging infrastructure, charging point

1 Introduction

Global atmospheric concentrations of Greenhouse Gases (GHG) such as CO_2, CH_4 and N_2O have increased markedly as a result of human activities since the industrial revolution and are drivers of climate change [1]. The transport sector as a whole contributed 20% (931 $MtCO_2e$) of total GHG emissions from the EU-27 countries [2]. Within the EU, transport is the second largest contributor to GHG emissions behind the energy sector. Notably, it is the only sector which has seen a rise of GHG emissions compared to 1990 levels and in 2004, transport accounted for 23% of energy-related GHG emissions worldwide [3]. Yet, transport is a key enabler for economic growth. The Eddington Review for example describes how increases in transport connectivity aid economic growth in developing countries [4]. It is important therefore to decouple economic growth from increases in greenhouse gas emissions. For that reason, central, regional and local governments have promoted climate change reduction targets that include electric vehicles. The European Parliament commits its member states to an ambitious climate change strategy reducing GHG emissions and energy consumption by at least 20% by 2020 using a 1990 baseline [5]. The UK is committed to limit its GHG emissions to below 16% in 2020 compared to 2005 levels [6].

North East England is at the forefront of low carbon vehicle development with Nissan manufacturing both the Nissan LEAF and Lithium-ion batteries at its Sunderland plant from 2013. Since 2010, the region has installed a comprehensive charging infrastructure and has become a major hub for vehicle and battery research and development, manufacturing, and training facilities, throughout the electric vehicle (EV) supply chain.

The charging infrastructure has been installed through Plugged in Places (PIP), a government funded programme operated by the Office for Low Emission Vehicles (OLEV) which has awarded funding to 8 areas within the UK in order to establish EV charging infrastructure to seed the uptake of low carbon vehicles. The aims of the programme are to feedback the experience gained by creating and operating EV charging infrastructure into future policy decisions at both

regional and national levels. This includes the development of standards, evaluation of technologies, harmonisation of local incentives, understanding users' behaviour and its impact upon the infrastructure.

North East England's Plugged in Places (NE PIP) project, called Charge Your Car (CYC), has created an integrated charging network for EVs spanning a region of 8,600 km^2, enabling EV journeys to become feasible across neighbouring regions in the UK, Scotland and Europe. By June 2013, the NE PIP project had installed 1163 charging points in public places, workplaces and in the homes of EV drivers across the region. The CYC estate includes a combination of 3, 7 and 22 kW AC charge points and, as one of the UK's EV industry pioneers, the north east was the first area to create a regional network of 50 kW DC quick charge points which enable EVs to be recharged to 80% in just 30 minutes. 12 quick chargers were installed by the NE PIP project at key staging points across the region.

The second key elements of the North East's electric vehicle activity is centred around 44 electric vehicles being trialled under the TSB Ultra-low carbon vehicle demonstrator (ULCVD) programme. The Switch EV trial brought together a consortium of vehicle manufacturers, data collection experts and project managers to deliver 44 new and innovative full- electric production vehicles onto the roads of the North East of England.

The Switch EV trial ran from November 2010 until May 2013. The vehicles were fitted with data loggers that provide a range of driving and vehicle performance data as well as GPS and a time stamp. These data points were collected and analysed at Newcastle University. In parallel driver attitudes towards EVs were gathered through questionnaires and focus groups. These two sets of data were then correlated to explore trends, changes in driving and charging behaviour and attitudes to electric vehicles, charging and key issues such as cost and 'range anxiety'. Most of the Switch EV drivers were also members of the CYC scheme and used the charging infrastructure created by the NE PIP project.

2 Methodology

The NE PIP project created a region-wide network of EV charge points, using multiple manufacturers' products, between April 2010 and June 2013. The estate combines 3, 7 and 22 kW AC and 50 kW DC rated charge points, with single and double outlets, located in public and workplace areas. Hosts were attracted to have charge points installed on their property by various levels of grant incentives covering equipment and installation costs. In exchange for this grant funding, each host provided free electricity and parking to EV drivers during the three year trial period which ended in June 2013. These charge point hosts now own the North East's EV charging infrastructure. In addition to this public and workplace infrastructure, the project also installed over 400 3 kW domestic chargers with captive cables for EV drivers in the region to use in their own home environment.

The vehicles used in the Switch EV trial were mostly commercially available vehicles, including Nissan LEAF, Peugeot iOn, Avid Cue-V, Liberty electric cars eRange, and the Smith Electric Vehicle Edison Minibus. Trial participants were a mixture of companies and Local Authorities who used the vehicles as part of their fleet as a pool vehicle or for the sole use for one individual. A small number of cars were also leased to private individuals.

2.1 Data Logging from electric cars

The hard data on the cars are derived from the controller area network (CAN) bus of the vehicle and transmitted to a secure database through wirelessly enabled data loggers within the car. Those data are overlaid with GPS and time stamps derived from an additional logging unit in the vehicle. The Avid Cue-V vehicles were equipped by Avid Analyticals with a logger that connects to the CAN bus through the vehicles on-board diagnostics (OBD) port. The Peugeot iOn vehicles were equipped with loggers provided by RDM. The loggers have been designed to take some external analogue and digital inputs. These inputs include the GPS and time-stamp data as well as a number of analogue inputs from current-clamps which are attached to various electrical systems of the vehicle to measure current flow and battery drain. Data that were collected included:

- Time/date – start, end and duration of events (for both trips and recharging events)
- Distance travelled
- Energy used per trip
- Energy transferred per recharge
- Recharging location (home, work, public charging infrastructure)

In this paper, home charging events have been removed from the Switch EV data set, in order to compare both data sets since the CYC data do not include home charging.

2.2 Data logging from charging infrastructure

EV drivers joined the project's CYC membership scheme at a cost of £100 per year or £10 per month. These members were issued with their own personal radio-frequency identification (RFID) card which had a unique tag identifier attached to it, enabling them to access all makes of public and workplace EV charge points across the North East region. All charge points had their own unique identifying code denoting:

- the charge point type (power delivery rating (3, 7 or 50 kW), single or double outlet),
- location category (on street, public place, workplace, commercial place)
- location id (latitude & longitude coordinates).

All public and workplace charge point activities were then recorded by the Back Office system managing the charge point network for the project, creating a charge point management system (CPMS). For each charging activity, the tag id, the transaction start and end date and time and the energy drawn were then transmitted via the GSM network to the Back Office operating the CPMS. Live charge point availability status was also displayed on the charge point location map, available to all users of the CPMS at www.chargeyourcar.org.uk to enable them to plan their EV journeys effectively. Both charge point owners and EV drivers also had access to their own charging data and history via a Members Portal within the CPMS.

The project also trialled Pay As You Go functionality using SMS techniques on all 12 quick chargers and some 3 and 7 kW charge points.

2.3 Soft data collection

Attitudinal data were collected through online pre- and post-driving questionnaires and focus groups. The driver recruitment process and dissemination of questionnaires is undertaken by Future Transport Systems, the data analysis is largely carried out by Newcastle University. The analysis is based on more than 100 responses from two 6-month trial periods that took place between March 2011 and April 2012. The number of drivers exceeds the number of vehicles because some of the vehicles are used as pool and fleet vehicles and multiple drivers have access to those vehicles.

3 Results

The Switch EV trial has seen 44 full electric vehicles cover over 400,000 miles across the North East of England, between March 2010 and May 2013, which account for over 90,000 journeys and over 19,000 charging events.

3.1 Electric vehicle driver profile

In order to understand the behaviour of the Switch EV triallists and whether there are some specific traits and choices associated with age, gender or demographics, a pre-trial questionnaire included questions to profile the participants. From this, it can be summarised that the majority of trial candidates were men with 72% of drivers bring male and 28% being female. Only 5% of drivers were 17-25 years old, 16% of drivers were 26-35 years old, 30% of drivers were 36-45 years old. The largest groups with 39% were 46-55 years old and a further 11% were 56-65 years old. The majority of drivers were married (63%). 91% of respondents were in full-time employment, 6% in part time employment, 3% self-employed and 1% full time students. This bias towards older male drivers is due to two characteristics of the trial, the first being the fact many of the vehicles were leased to triallists to use at work (either being an individual work users vehicle, or a pool vehicle shared by a number of workplace colleagues), and the age profile (particularly of the individual, private triallists was quite high – this is largely correlated with the actual costs of leasing the electric vehicles. Further research showed that the profile of the SwitchEV drivers fits well into the general EV purchasing behaviour. According to the DfT, 87% of recipients of the Plugged in car grant were male, working full time (in senior roles or self-employed) or retired and aged 40 years and above [7].

3.2 Perception of the electric car

Over the course of the Switch EV project, 192 participants provided answers to the pre-trial questionnaire, 101 answers to the post-trial questionnaire and 30 answers to quick charger questionnaire. In addition, 60 participants attended 12 focus groups; 12 individual exit interviews and 10 pre-trial interviews were conducted in order to

understand drivers' attitudes towards electric vehicles and their charging infrastructure. Quotes from the drivers that have been reproduced from their questionnaire reposes or captured from the oral record of the focus groups are presented in quotes: "…".

As shown in Figure 1, the key barriers to the uptake of electric vehicles can be summarised in three points: (1) Cost of the vehicle, (2) Limited driving range of the vehicle and (3) Concerns about re-charging (time required for charging and availability of charging infrastructure).

Before the trial, many drivers reported that they thought electric cars looked *"Small"*, that *"They're almost like Dinky toys."* or that they *"were like a milk floats".* These perceptions changed dramatically after they had driven the Switch EV cars. In the post-trial questionnaire, drivers said: "*I thought it was very, very comfortable, very easy to drive.".* Another driver said: *"I found it was better than any car I've ever driven before."* A pool car driver commented how he first had to be convinced of the car: *"I saw the EV actually a couple of days ago because our Chief Exec's decided to drive one and I was actually surprised at the size of it. It looks a lot chunkier than I would have expected.*" Most EV drivers commented that the benefits of driving an EV were free parking and low running costs of the cars.

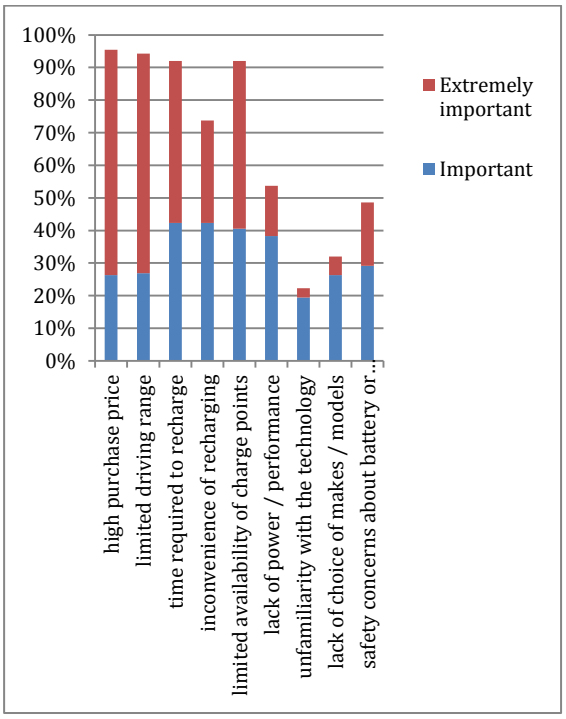

Figure 1 Perceived barriers to the uptake of electric vehicles

Overall, 80% of drivers thought that the overall experience of driving an EV was either the same or even better than that of driving an internal combustion engine (ICE) car, as shown in Figure 2. 20% of drivers thought it was worse than driving an EV. One driver explained in the focus group: "*I would say that the range must be probably the biggest barrier. If it's your only mode of transport then it probably is a problem, but not if it's for use as a second vehicle.*"

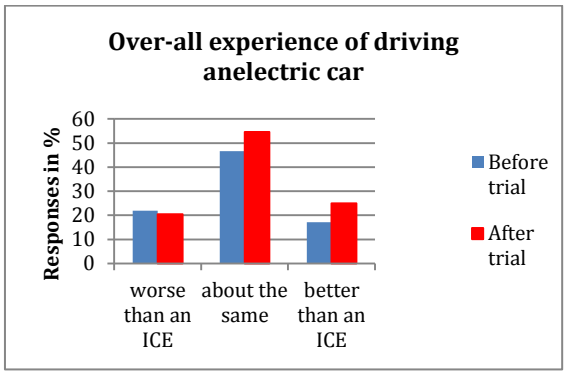

Figure 2 Answers to the questions 'How do you expect the over-all experience of driving the electric car? in the pre-trial questionnaire and the question 'How was the over-all experience of driving an EV?' in the post-trial questionnaire

Following the end of the drivers' participation in the trial, 16% of drivers said that they would consider buying an EV as a primary car and 46% of drivers said that they would consider buying an EV as their second car. Significantly only 38% of drivers said that they would not yet consider buying an EV. Most of them thought that the cars were still too expensive and they were unsure about how/if the battery would degrade over time.

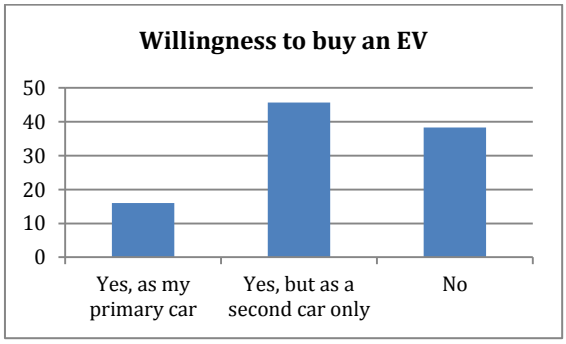

Figure 3 Answers to the question: "Would you consider buying an EV?" in the post-trial questionnaire

3.3 Driving behaviour of Switch EV drivers

In Figure 4, the distribution of journey distances is shown. It shows that there is a small peak at around the 2-3 km point, representing the point at which vehicles will begin to be used for journeys rather than parking manoeuvres. After this point there is a gradual reduction in the number of journeys as the length of the journey increases. Notably, only 2% of the recorded journeys are longer than 25 miles. However, since 2002, the Department for Transport (DfT) conducts a national travel survey every year through face-to-face interview and a one week self-completed written travel diary with approximately 20,000 individuals, in 8,000 households [8]. Their results show, that 93% of all journeys in the UK are within 25 miles, showing that EV drivers use their cars very similarly to the English public as a whole.

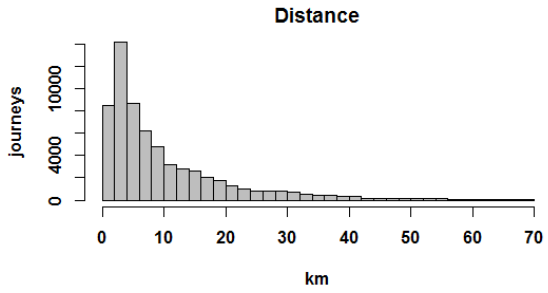

Figure 4 The distribution of journey distances. For clarity the small number of journeys greater than 70km have been omitted.

Within the Switch EV trial the electric vehicles were distributed to multiple different people and companies. In general the use of the vehicles then fell into two separate categories:

a) Pool Users. The vehicle was available as a shared resource, accessible to multiple different people over the course of that particular deployment. Typically the vehicle would be managed by either the general fleet operator of an organisation or company, or someone else in an equivalent responsible position.
b) Single User. The vehicle was driven by a single user, who would also be typically responsible for the safe storage, charging etc. of the vehicle.

It was expected that the two groups might use the vehicles differently. Single users for example were thought to get used to the electric car more easily and that they might overcome range anxiety more quickly and therefore drive further, use more in-car technologies such as heaters that use energy and charge less frequently. The pool car users on the other hand were often told by their employer that they had to charge the vehicle every time they returned back to the depot.

Table 1 shows the variations between the two user groups.

	Pool users	Single users	Statistically significant
Journey Distance (km)	8.13	9.99	Yes
Duration (min)	15 min	15 min	No
Efficiency (kWh/km)	0.163	0.180	Yes
Energy per Trip (kWh)	1.24	1.48	Yes
Speed (km/h)	32.6	39.8	Yes

Table 1 Average Usage and Performance Statistics by Vehicle User Type

It can be seen from the average usage of the vehicles by pool and individual users in Table 1 that, on average, the pool user vehicles are slightly more efficient (by ~15%) than the single user cars. In addition they travel slightly less far per journey, use less energy per journey and driver slower. The authors concluded that essentially the Pool users are driving for slightly shorter distance at a slower speed which leads to a statistically identical overall duration.

3.4 Charging behaviour of Switch EV drivers

With more than 90,000 journeys and 19,000 charging events recorded and an associated 120 MWh energy transferred, the Switch EV project resulted in an extensive and unique dataset on the charging behaviour of electric vehicle users.

30% of drivers in the post-driving questionnaire stated that they recharged their car twice a day and 11% of respondents said that they recharged their car as often as possible. While the data loggers show that the actual recharging frequency was lower than the self-reported charging frequency, 17% of drivers still recharge twice a day. Analysis of the trial data shows that 30% of charge events in the North East of England took place at public charge posts, primarily during peak electricity demand hours. Further analysis of the charge

events revealed that nearly 20% of EV users seemed to be using the public charging infrastructure as their primary means of charging.

One EV driver confirmed this in the focus groups: "*We're lucky enough to have some public infrastructure right beside where we work so that we just plug it in really while we work and then take it home … I've never charged it on anything else apart from public infrastructure so that's been the source for all our charging – or all my charging anyway.*" Another driver explained why they used public charging infrastructure mostly to charge the vehicle: "*I've been parking [at a charge post in the city centre] which has been a godsend. My office is 25 feet away, and parking is free; so this car has actually paid us. We have saved money by renting the car*". Other drivers said that they enjoyed the convenience of parking at the EV charging bays: "*I take the EV not because I'm going to get a free parking space. It's just convenience. There are lots of them [charging posts], they're in good locations and I know I can get one and it's convenience rather than cost.*" Not surprisingly, most drivers therefore said that the access to public standard chargers and public quick chargers was either very important or quite important as shown in Figure 5.

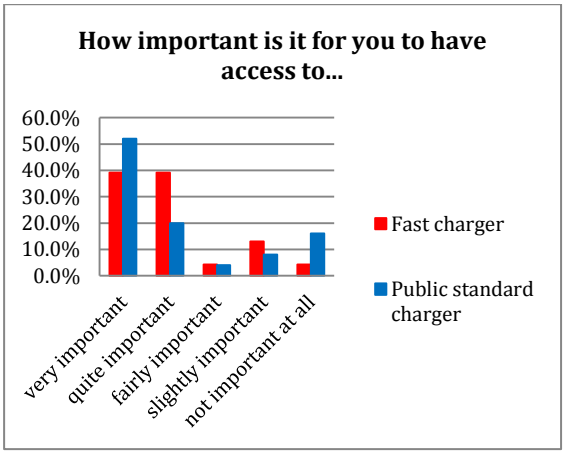

Figure 5 Answers to the question of the post-driving questionnaire 'How important is it for you to have access to quick chargers and public standard chargers?'

3.5 Public charging behaviour

In order to meet the EV drivers' demand for public charging infrastructure, the NE PIP project has installed 1,163 charge points up to the end of June 2013. The composition of the estate at that time is illustrated in Figure 6.

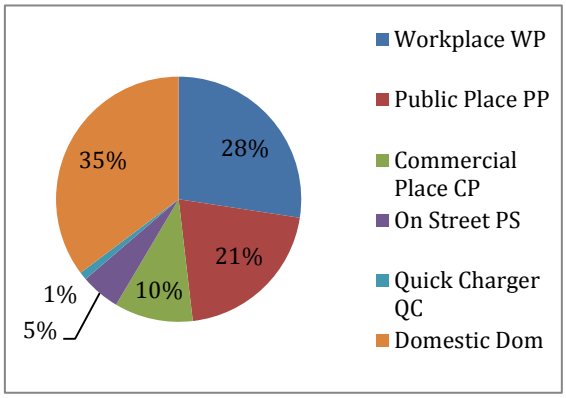

Figure 6 NE PIP Estate charge point composition by location type, June 2013.

The NE PIP estate delivered over 35,000 charging transactions and over 250 MWh of energy to EV drivers until the end of March 2013. This equates to approximately 400 metric tonnes of carbon savings.

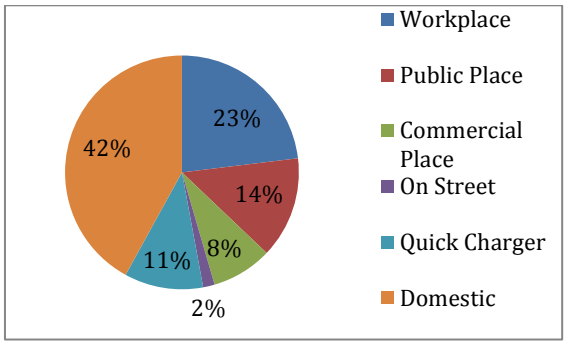

Figure 7 NE PIP Energy delivered to March 2013.

The proportion of energy delivered by location category is shown in Figure 7. As can be seen, the 50 kW DC Quick Chargers delivered a much higher proportion of the total energy provided by the estate (11%) than their composition proportion suggests (1%). Conversely, the 3 and 7 kW charge points in public, commercial places and on streets deliver a much lower proportion of the total energy (a combined 24%) compared to their composition (a combined 36%). The domestic chargers make up 35% of the estate but have delivered 42% of the energy.

One of the reasons for this is the difference in usage patterns throughout the week as shown in Figure 8. Charging events at the workplace

chargers fell markedly at the weekend, similar to those of public, commercial and on street charging points. However the number of charging events on the quick chargers remained relatively constant throughout the full 7 days of the week.

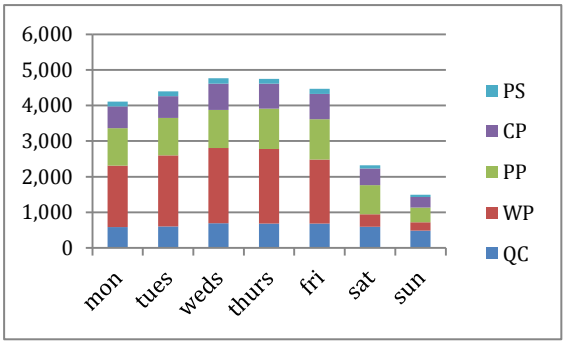

Figure 8 CYC Estate transactions, the number of charging events by day of the week.

Secondly, the energy transferred per charge event differs between the different charging point location types. On average, the energy delivered per transaction on the 3 and 7 kW chargers in the CYC estate was 6 kWh, rising to 8 kWh on the quick chargers and 12 kWh on the domestic chargers.

To date there has been marginally more energy delivered by the CYC estate (58%) than by the domestic chargers (42%). However, as Figure 9 shows there has been a marked increase in domestic charger installations over the last 6 months.

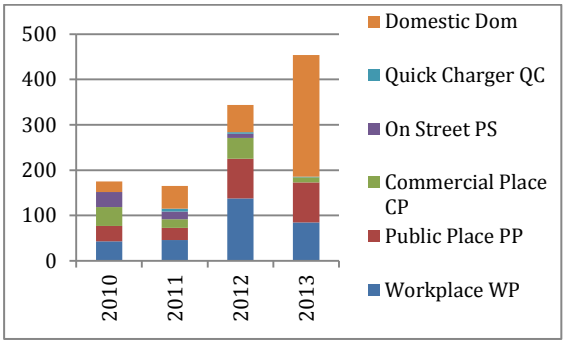

Figure 9 NE PIP Estate charge point installations by year.

Therefore it will be interesting to monitor how the proportionate use of the CYC estate versus domestic charge points changes in the coming months and years. Changing habits are also likely to be impacted by the removal of financial incentives such as free parking which will begin in the North East over the next few months. With the end of the NE PIP project, the CYC estate must now become self-sustaining and its hosts will therefore be able to charge EV drivers for the use of their EV charging facilities, as a way of recouping their up-front capital investment and on-going operating costs. Some North East hosts however are considering continuing to provide financial incentives as a way of attracting EV drivers to their facilities, whether employees or members of the public, as a contribution to their sustainable transport plans. Workplace hosts are likely to retain the free electricity offer for their employees, but this may change in the future if the Government's approach to employee benefits in kind changes.

4 The North East of England's approach to Low Carbon Vehicles

The North East of England has become one of Europe's most established low carbon vehicle demonstrator regions through its knowledge and manufacturing base throughout the low carbon supply chain. The following projects and developments have been selected to provide a small glimpse into the capabilities of the region:

- the mass-manufacture of one of the world's leading electric vehicles, the Nissan LEAF, and Li-ion batteries;
- an already developed charging network, pioneering research, product and service development, training, testing and trialling of all aspects of low carbon vehicles;
- a history of electric vehicle demonstration trials such as Switch EV and smartCEM;
- Customer-Led Network Revolution, the UK's biggest smart grid project is helping customers find ways to reduce their energy costs and carbon emissions in the years to come [9].
- UK wide EV quick charger roll-out programmes, and the creation of a multi-standard quick charger UK network, including the German Combo standard, which will link with the Irish e-Cars programme through TEN-T.
- development of Charge Your Car Limited, the UK's first national pay as you go recharging network [10].
- a thriving culture of research and development by local SMEs which have

received match-funding support to develop new products and create or safeguard skilled jobs. Over the last six years more than £250 million has been invested in developing our world-leading expertise in this emerging technology and the region has gained an international reputation
- development and manufacture of low carbon vehicles. This investment to date has ensured that the region is geared up and ready to enable the switchover from the internal combustion engine to low carbon driving.

5 Conclusions

The electric vehicle trials in the North East of England were unique in that, drivers of EV were allowed a comprehensive choice of infrastructure (public, work and domestic). This allowed behaviour to be monitored through quantitative data on vehicle and charging equipment use. The Switch EV trial has seen 44 full electric vehicles cover over 400,000 miles across the North East of England, between March 2010 and May 2013, which account for over 90,000 journeys and over 19,000 charging events. The 1,163 CYC charge points have delivered over 35,000 charging transactions and over 250 MWh of energy to EV drivers until the end of March 2013.

The data collected and analysed shows clear patterns of behaviour, however these patterns were in part impacted by external influences, such as free parking with the CYC membership and further analysis of EV driving and charging behaviour will be performed now that the CYC membership and payment system is changing.

There have been many benefits resulting from the NE PIP project and Switch EV trial working together over the last 3 years. A number of these are set out below.

A high number of charging transactions have been recorded both by the EV data loggers and the charge point management systems. This has resulted in a rich seam of data with an opportunity for a method of verification and validation which is uncommon in such trials. The results of this analysis will inform future policy making at regional and national levels, and will enable future EV trials to target specific aspects of EV use and charging behaviour.

A common barrier to EV trials, the lack of charging facilities, was removed by NE PIP providing Switch EV participants with home chargers and an established network of public charging infrastructure spanning the region. Switch EV calculated that their drivers were within 15 km of a CYC charge point for over 99% of the time spent driving.

The NE PIP project was the first to create a membership access scheme with a live availability charge point map, as well as drivers' usage information.

The NE PIP project was heavily involved with the IET in the creation of suitable standards for EV infrastructure, culminating in the IET's Code of Practice for Electric Vehicle Charging Equipment Installation in 2012.

On-going feedback from both trial participants and suppliers greatly contributed towards the creation of qualifications and specific training packages for those involved in the EV market, from first responders to EV dealers, technicians, infrastructure installers and maintainers.

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Acknowledgments

The authors gratefully acknowledge the funding support of the Technology Strategy Board, the Office for Low Emission Vehicles (OLEV) and ONE North East and the support of all the Switch EV partners in the project: Nissan, Simon Bailes Peugeot, Avid Vehicles, Smiths Electric Vehicles, Liberty Electric Vehicles, Charge Your Car, Zero Carbon Futures and Future Transport Systems.

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