Centre of excellence

for low carbon and fuel cell technologies

the smart move trial

description and initial results

Authored by
Steve Carroll, Technical Specialist

Authorised by
Chris Walsh, Head of Technical and Consultancy

Executive summary

Cenex, the UK's first Centre of Excellence for low carbon vehicle technologies deployed four electric passenger cars in the North East of England with the aim of studying the integration of electric vehicles into fleets, accelerating the adoption of electric vehicles in the area and studying the efficiency and performance of the vehicles.

During the six month trial, organisations took part by integrating one to four electric two seater passenger cars into their fleets and allowing qualitative and quantitative data to be collected. The key findings and conclusions are drawn from a robust data sample covering

- electric vehicle integration into ten different vehicle fleets
- a total of 190 questionnaires returned from the 264 different individuals who drove the vehicles during the trial
- three drive events capturing the opinions of the general public both before and after a test drive in an electric vehicle.

Data analysis shows that the operating regime used by vehicle fleets could provide a successful 'early adopter' market for electric vehicles. Questionnaire data shows the 58% of fleet users felt more positive about electric vehicles after the trial and 88% of fleet managers felt more positive about incorporating electric vehicles into fleets, stating that the lack of public charging infrastructure was not a barrier to fleet integration.

Drive data shows that users were over cautious when planning journeys. The maximum journey length undertaken was only 25% of the average vehicle range. Range anxiety effects were significant throughout the trial with 93% of journeys commencing with over 50% battery state of charge. Data suggests that users modify their driving style when battery state of charge reduces below 50%. The study highlights the need for more sophisticated range prediction aids onboard electric vehicles especially as the number of vehicles available to the market increases. Vehicle operators with dedicated charging posts installed rated their charging experience higher and managed charging aspects of the vehicles more efficiency than organisations without.

During test drives the electric vehicle exceeded the general public's expectations on all monitored performance criteria leading to 72% of the drivers stating they would use an electric vehicle as their regular car compared to 47% before the test drive. Test drivers and fleet users in the 20 to 30 age group experienced the highest opinion shift in favour of electric vehicle ownership.

The average range achievable from the electric vehicles was 72.4 km emitting 81.4 g CO_2/km when recharged with UK average grid mix electricity. If charged with lower carbon sources of electricity, the vehicles achieve average emissions of 45.0 g CO_2/km from Combined Heat and Power, and 0 g CO_2/km from renewable electricity. The current UK Government incentives to decarbonise the electricity network will coincide with advancements and the mass market introduction of electric vehicles offering an inherently low carbon future for EVs.

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1 Introduction

Cenex, the UK's first Centre of Excellence for low carbon and fuel cell technologies is a delivery agency established with support from the Department for Business, Innovations and Skills (BIS). Cenex's principle focus is catalysing market transformation projects linking technology providers and end users. As part of this work Cenex runs a number of programmes for UK national and regional government promoting and deploying low carbon vehicle technologies.

This report presents the methodology, results and conclusion of a six month electric vehicle trial during which Cenex worked with and enabled organisations in the North East of England to experience firsthand how electric vehicles can be integrated into fleets. Dependent on the organisation and their needs, one to four electric passenger cars were loaned for a period of up to one month.

The trial tests the hypothesis that organisations that operate vehicle pools and fleets are ideal candidates as early adopters of electric vehicles. The trial seeks to accelerate the adoption of electric vehicles in the area and study the carbon footprint and performance of the vehicles.

It was found that vehicle users and fleet managers felt more positive about electric vehicles after taking part in the trial. The performance aspects of the vehicles were rated as 'Good' with fleet users finding the charging aspects easy and intuitive. Organisations with access to dedicated recharging points rated their experience higher than organisations without and also managed charging more efficiently allowing the vehicles to keep 'topped up' more between drives.

Electric vehicles are suited to the return-to-base operations of fleets and 88% of fleet managers did not see the lack of public recharging infrastructure as a barrier to incorporating electric vehicles (EVs) into their operations.

Range anxiety effects were significant during the trial with users being over cautious when planning which journeys were achievable to the extent that the maximum journey length undertaken was only 25% of the average range.

The average range achievable from the electric vehicles was 72.4 km emitting 81.4 g CO_2/km when recharged with UK average grid mix electricity. If charged with cleaner sources of electricity, the vehicles achieve average emissions of 45.0 g CO_2/km from CHP (combined heat and power) and 0 g CO_2/km from renewable electricity. The variation in range was +/- 40 km depending on operating conditions.

The smart move trial was funded by the department for Business Innovation and Skills and delivered by Cenex in conjunction with One North East, the regional development agency for the North East of England. Newcastle University's Transport Operations and Research Group provided data logging and technical support. Future Transport Systems (FTS) provided trial management support and regional contacts. Gateshead, Newcastle, Sunderland, Stockton-on-Tees and Durham County Council provided operational bases for the vehicles while they were operated within the North East.

The information gained in this study will be disseminated by Cenex to allow organisations to gain an understanding of the capability and performance of EVs in fleets nationwide.

2 Trial aims

Cenex deployed four electric vehicles in the North East, the UK's Low carbon economic area for ultra low carbon vehicles. The vehicles were active in the area for 6 months and the aims of the trial are stated below.

- Study the integration of electric vehicles into fleets.
- Accelerate the adoption of electric vehicles in the area.
- Study the efficiency and performance of the vehicles.

The trial set out to test the hypothesis that organisations that operate vehicle pools and fleets are ideal candidates as early adopters of electric vehicles. This hypothesis exists because vehicle usage patterns in fleets are normally more predictable and planned than those of private users. The more frequent and intensive travel requirements of fleets lend themselves to vehicles being more easily and economically restricted to certain applications. Fleets also operate a return-to-base operation where only a limited amount of recharging infrastructure needs to be installed.

3 The vehicles

The vehicles deployed on the trial were four electric smart fortwo passenger cars. The smarts were released in 2007 as part of a pilot production run from Mercedes which saw 100 electric smart fortwo cars being deployed throughout the UK. A brief specification of the vehicle is detailed in Table 1 below.

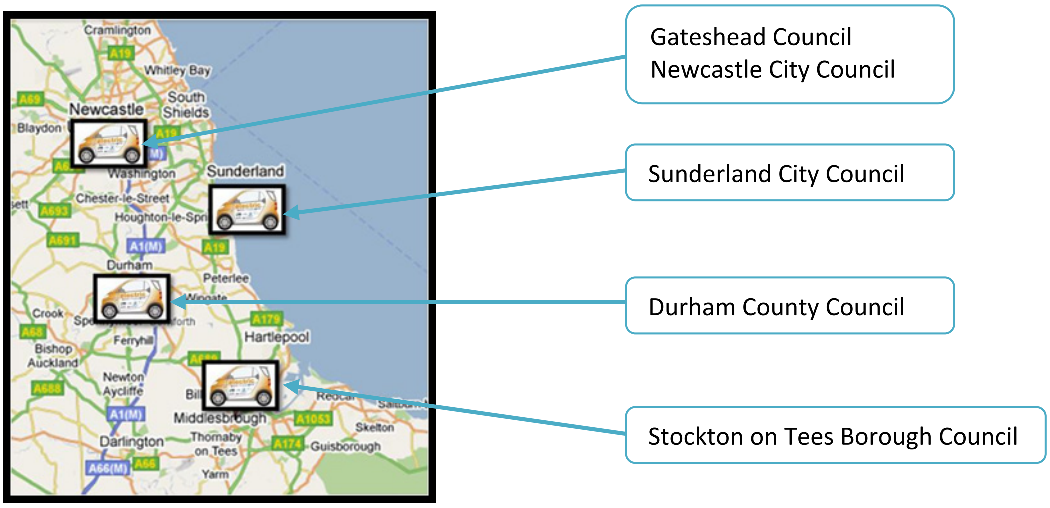
Table 1 - Electric vehicle specifications	
Make	smart (Mercedes)
Model	Fortwo ed (electric drive)
Motor power	20 kW
Energy storage capacity	15 kwh
Battery chemistry	Sodium nickel chloride
Top speed	Restricted to 60 mph
Charge supply	13 amps at 240v

Although this was the only model of electric vehicle used in the trial, the key learning outcomes are relevant to EV deployment and integration issues for a wide range of electric vehicles.

4 Vehicle deployment

The safe and efficient management of the vehicles on trial was a key aspect of operational success. Partnerships were formed with environmentally aware and enthusiastic local councils within the area. These local authorities acted as electric vehicle hubs that could support the deployment and management of the vehicles to participating organisations within their area. This enabled the participating organisations to attend user inductions and vehicle safety checks given from a local base. The location and participating councils are shown in Figure 1 below

Figure 1 - Locations of electric vehicle hubs



Organisations wishing to participate in the trial were invited to fill in a pre-qualification questionnaire. This allowed formal characterisation of vehicle duties and usage patterns which enabled fleets to be selected for trial involvement thereby ensuring that a broad usage pattern existed within the data collected.

To complement the fleet integration data and to further promote electric vehicles in the region, three drive events took place allowing members of the public to experience driving electric vehicles first hand. All four vehicles were deployed to the drive event days, where professional drivers accompanied members of the public on a planned route.

5 Data collection systems

Quantitative and qualitative data capture systems were put in place to monitor and record performance and perception issues of integrating EVs into fleets. The data systems were designed to capture relevant information about how the vehicles interacted with and performed in the environment in which they were placed.

5.1 Qualitative data

To gain information on the perception and attitudes towards the electric vehicles, three questionnaires were designed.

A **Fleet user questionnaire** was issued to all drivers of the smarts during the fleet trials to gain feedback on the perceived performance of the vehicle, the recharging infrastructure and how this affected the users' opinions of electric vehicles.

A **Fleet manager questionnaire** was issued to each user company for feedback on management experiences during the trial. The questionnaire focused on items such as an organisations motives for integrating electric vehicles into its fleet and the perceived advantages and disadvantages from a fleet managers' perspective based on their experiences during the trial.

A **Public drive event questionnaire** was issued to members of the public attending a test drive day. The drivers rated their expectations of the performance from the electric vehicle before the test drive and then reassessed against the same performance criteria post test drive.

5.2 Quantitative data

To capture detailed information on vehicle performance and energy demands telemetry and data logging equipment was fitted to the smarts by Newcastle University's Transport Operations Research Group. The data loggers were configured to read information from vehicle sensors available on the smart's CAN (Control Area Network) bus and store this data in the logger's internal memory along with vehicle GPS (Global Positioning System) position. Each time the ignition was turned off, the data stored from the previous journey was remotely downloaded via the GSM (Global System for Mobile Communications) network to a server at Newcastle University. The following information was recorded from the vehicles.

- Positive and negative power flow across the battery terminals.
- Battery state of charge.
- Vehicle GPS position.
- Ancillary load state.
- Ignition position.
- Brake pedal state.
- Ambient temperature.

Journey data was logged once per second when the vehicle ignition was on and charge data was logged once per minute whilst the ignition was off.

6 Qualitative data analysis

This section examines the questionnaires returned from vehicle users and trial participants. Key findings are brought out of the discussion and summarised at the start of each section to allow ease of access to the main results for the reader. These findings can be used to inform organisations and policy makers of the aspects which contribute to successful EV deployment and integration.

6.1 Vehicle fleet users

The following section details the analysis of the fleet user questionnaires, these were the questionnaires issued to all the drivers of the vehicles during the fleet trials.

Table 2 below gives summary data for the number and type of organisations which integrated the EVs into their fleets.

Table 2 - Organisation summary data

Organisation type	No of organisations in study	Number of different drivers	Number of questionnaire returns
Local council	7	149	92
Private company	2	16	14
University	1	12	7
Total	**10**	**195**	**113 (58% return rate)**

The users rated different performance aspects of the vehicle and their experiences recharging the vehicles with the scoring criteria detailed in Table 3 below.

Table 3 - Fleet user questionnaire assessment key

Score	Performance descriptor
1	Bad
2	Poor
3	Acceptable
4	Good
5	Excellent

6.1.1 Perception of EV performance

Fleet users were asked to rate the performance of the vehicle on a number of aspects, the key findings from the analysis are summarised below.

Key findings

- **Users rated the overall performance of the EV as 'Good'. Users rated the noise level and the environmental feel good factor of the EV more positively than other performance criteria.**
- **Most variation in answers received was observed in the noise category. This represented a split in opinions between the environmental improvements and the public safety concerns associated with low noise emission vehicles.**

Users of the vehicles were asked to rate the performance of the EV compared with a similar class fossil fuelled vehicle with conventional drive chain technology using the scoring methodology given in Table 3 above. Below are the performance criteria the users rated, together with a brief justification for their inclusion.

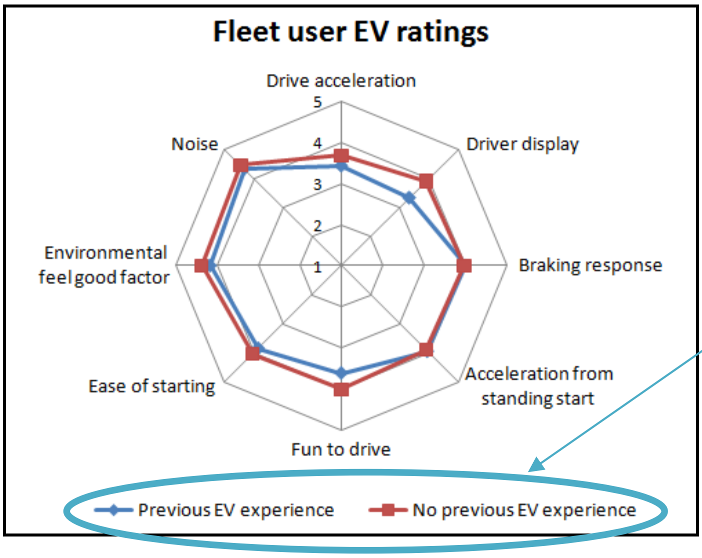
Table 4 - EV performance criteria aspects

Performance criteria	Justification
Drive acceleration	For electric vehicles to gain mass market acceptance the performance and drive aspects should be similar or superior to conventional vehicle technology.
Standing acceleration	
Fun to drive	
Ease of starting	
Driver display	Driver feedback is an important part of driving an electric vehicle, a prominent battery state of charge display and an onboard feedback system for driving efficiency helps users to maximise range.
Braking response	Regenerative braking can cause a different braking feel to a conventional vehicle.
Environmental feel good factor	Assesses whether green credentials associated with electric vehicles improve the drive experience.
Noise	Aims to assess user perception of the low noise aspects of an electric vehicle.

Across all performance aspects the users rated the vehicle as a 4 (= 'Good'). Drive acceleration and driver display were marked lowest and noise and environmental feel good factor were rated highest. There were no significantly major deviations from the perception of 'Good'.

Figure 2 below shows that users with no prior experience of electric vehicles were more enthusiastic about the EV than users with previous EV experience. Experienced drivers marked the driver display aspects lower, here the users without EV experience would be unaware of the benefits of driver aids showing regeneration and power usage which are common place in most electric vehicles.

Figure 2 - Fleet user EV ratings



The overall performance of the vehicle was rated at 4, which represents 'Good'.

Users with no prior experience of electric vehicles were more enthusiastic about the EV than users with with previous EV experience

The pattern of performance ratings did not change significantly in the fleet user data when analysed by gender, age or organisation. There was most variation in user scores in the noise category, which can be explained through additional user comments where some perceived the low noise emissions as an environmental improvement and others as a cause for concern due to health and safety aspects of a quiet drive operation.

6.1.2 Fleet user recharging assessment

This section examines how users rated the charging aspects of the vehicle trial and assesses how well participating organisations and users managed the charging aspects of the vehicle/s. A wide variety of charging regimes have been used and evaluated throughout the trial as dedicated infrastructure is not currently widely available.

Key findings

- **Users rated their charging experience as 'Good'.**
- **Predominantly return-to-base charging at work was employed throughout the trial.**
- **Public sector fleets scored recharging aspects 9 % higher than private sector fleets.**
- **Half of the public sector fleets had some access to dedicated recharging infrastructure and rated charging facility availability and safety 20% and 13% higher than private fleets respectively.**
- **The vehicles were generally well managed and there were no instances where users ran out of charge during a journey although 34% of users had experienced moments where they felt the vehicle may not have had enough charge for their intended journey.**
- **73% of users in fleets with access to dedicated recharging infrastructure found the vehicle on charge (topping-up) before use compared to 42% in fleets without recharging infrastructure.**

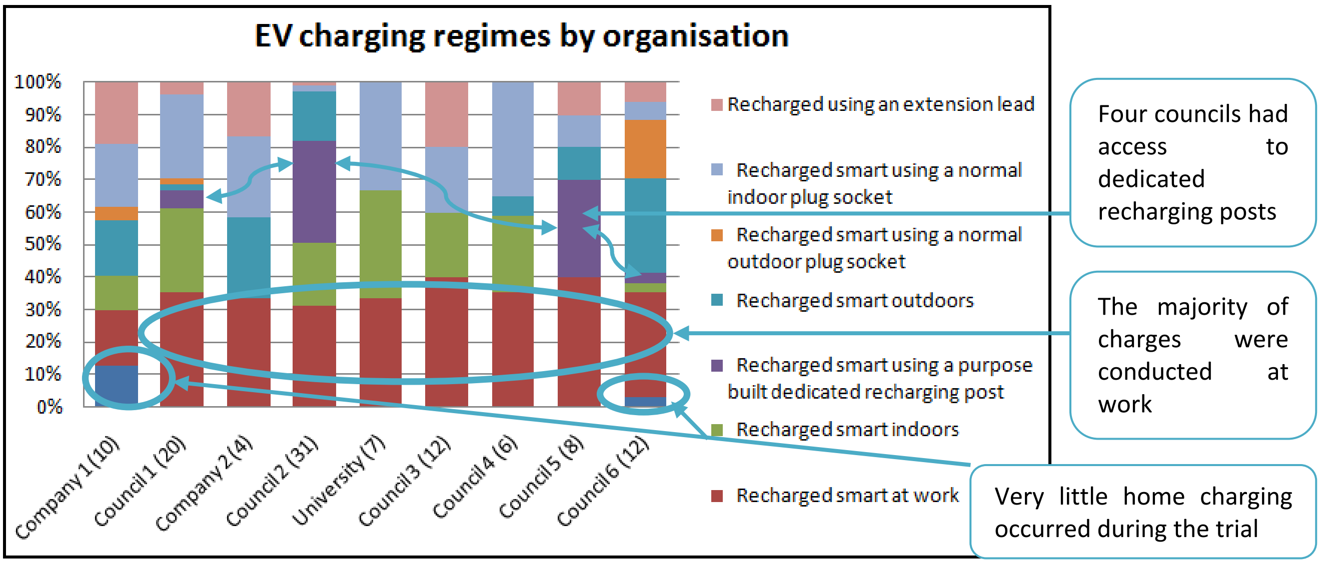
On each fleet user questionnaire the type of equipment used and charging method was noted. Table 5 below summarises the different charging regimes used. Some users may have experienced all the charging regimes whilst others only a few, therefore there is no simple correlation here with the absolute number of charging events or the number of fleet users. Other than compliance with UK law and health and safety legislation, no restrictions were placed on the methods or equipment used to recharge the EVs.

Table 5 - Recharging method, equipment and frequency

Recharging regime description	Number of recharging regime experiences
Recharged at work	86
Recharged indoors	45
Recharged using dedicated recharging facilities	38
Recharged outdoors	39
Recharged using a normal indoor plug socket	39
Recharged using an extension lead	18
Recharged using a normal outdoor plug socket	9
Recharged at home	7
Total	**281**

Figure 3 below shows the split of charging regimes used by organisations and the number of questionnaire returns obtained in brackets after the organisation description. Here it is shown that the majority of users recharged the vehicle at work. A mix of indoor and outdoor charging was used. Four organisations had access to purpose built dedicated recharging posts.

Figure 3 - EV charging regimes colour frequency chart



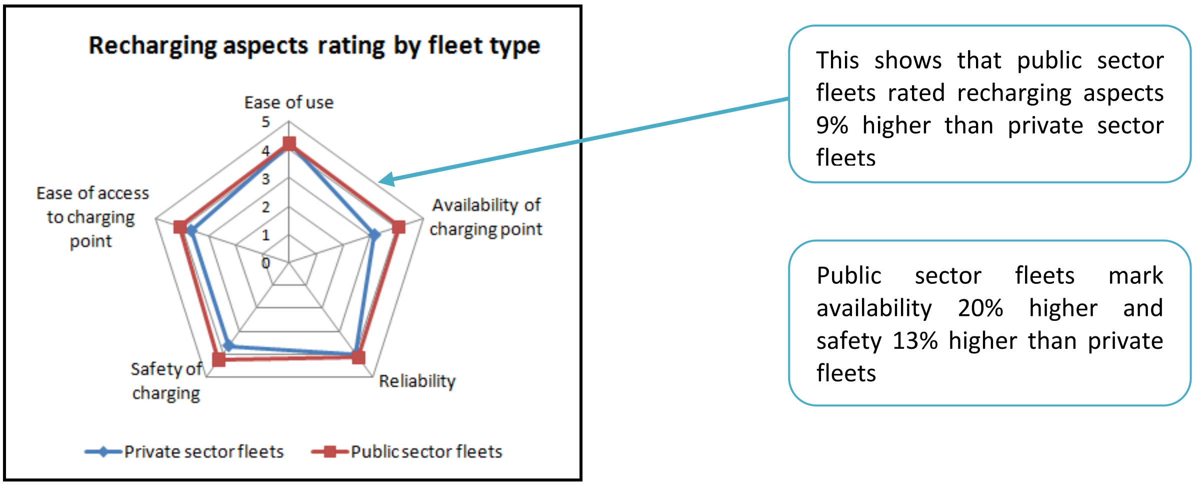
Fleet users rated recharging aspects using the same 1 to 5 scale (bad to excellent) as in the drive performance analysis detailed in Table 3 above. The average score obtained for each charging aspect studied is detailed below in Table 6.

Table 6 - Fleet user recharging aspect scores	
Recharging aspect	**Average score**
Ease of access to charging point	4.1
Ease of use	3.9
Availability of charging point	4.1
Safety of charging	4.2
Reliability of charging	4.2

The fleet users rated their charging experiences as ‘Good’ (score 4.1), finding charging the vehicle was easy, safe and reliable with only minor differences in opinion existing between age, gender and organisations. The positive attitude towards charging shows that the users accepted the electric vehicle charging requirements, and did not draw comparison to refilling a conventional vehicle with fuel.

Figure 4 below shows that public fleet operators rated recharging aspects higher that private operators with the most significant aspect being the availability of the charging points and to a lesser extent, the safety of vehicle recharging. This shift in attitude may be reflecting the difference in charging equipment used as 50% of the local councils had some access to dedicated recharging infrastructure.

Figure 4 - Fleet user recharging aspects radial chart



The data also showed a minor trend that charging aspects scored higher with older age groups and users that did not use extension leads.

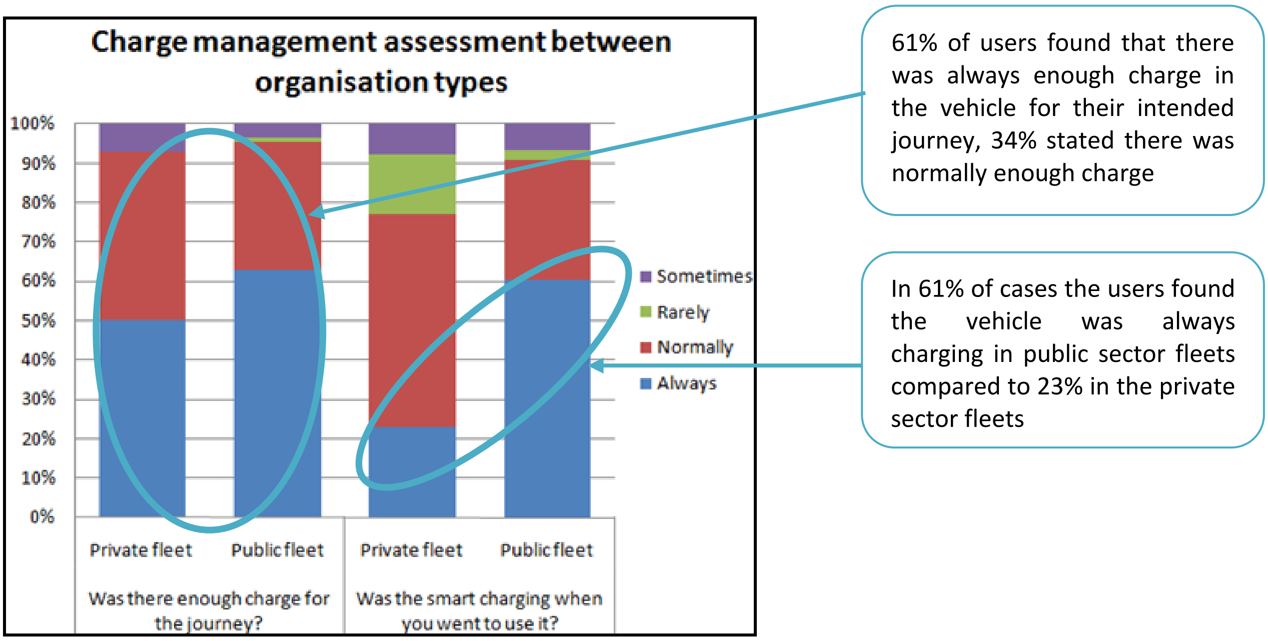
6.1.2.1 Charge management

The range available from a fully charged electric vehicle is low when compared to a conventionally fuelled vehicle. Poor charge management of the vehicles can lead to a further reduction in available mileage as vehicles are dispatched on journeys with a low battery state of charge. This charge management issue is particularly relevant for the smart EV as the battery technology employed consumes energy for internal battery heating to maintain the battery at it's working temperature.

The fleet user questionnaire asked users to rate how often the vehicles were on charge before their journey and if there was sufficient charge in the vehicles for the intended journey. The users could answer these questions by choosing either 'Always', 'Normally', 'Sometimes' or 'Rarely'. These qualitative ratings were designed to allow analysis of how the charging regime was managed by the organisation taking part in the trial.

Figure 5 below indicates that the charging regimes were generally well managed but opportunities exist for charge management and hence available journey range to be improved.

Figure 5 - Fleet user charge management assessment chart



The chart above shows 95% of users thought that there was always or normally sufficient charge available for their intended journey. This included 34% of the fleet users who doubted the vehicle could accomplish certain journeys due to the state of charge at journey start. This may have been reduced if the vehicles were more vigilantly put on top up charge between journeys. There is a clear trend in the data showing journey planning was managed more effectively in public fleets than in private fleets. This trend also correlates to the charging aspects analysis where the availability of recharging points was rated higher in public fleets where 50% of the organisations had some access to dedicated recharging posts.

6.1.3 Perception change after trial

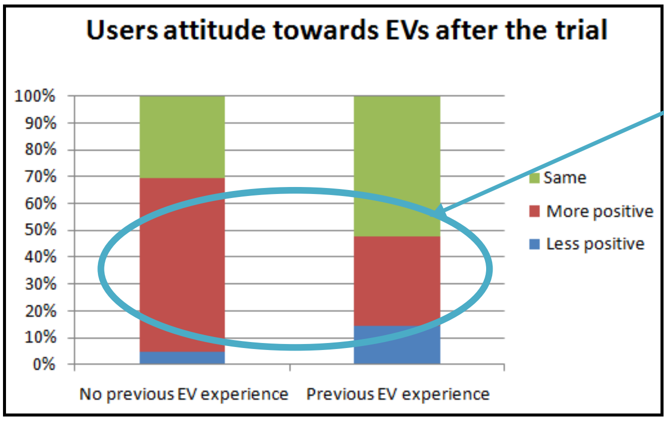
The fleet users were asked to rate how their experiences taking part in the trial had altered their perception of electric vehicles.

Key findings • **58% of users felt more positive about electric vehicles after taking part in the trial.** • **Users in their 20s experience the highest opinion shift of all the age groups with 83% of users feeling more positive about electric vehicles after their trial experience.**

The fleet users were asked to rate whether their experience in the trial had made them feel 'Less positive', 'More positive' or 'The same' about electric vehicles.

Figure 6 below shows that the majority of fleet users felt more positive about electric vehicles after the trial. The shift in attitude was greater for users that had no previous experience with electric vehicles.

Figure 6 - Fleet user attitudes chart

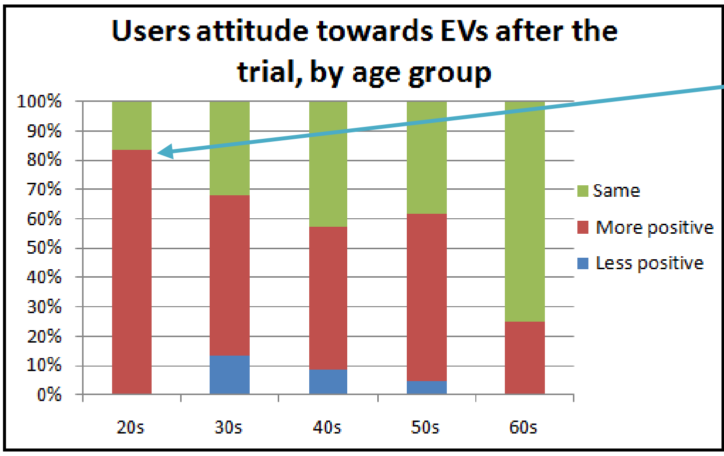


58% of users feel more positive about electric vehicles after participating in the trial

53% of fleet users with previous EV experience did not alter their opinion on EVs after driving the vehicle

Figure 7 below shows that the EV experience has the most impact on the attitude of younger users. This agrees with an observation in the public test drive questionnaires where drivers in their 20s have the largest change in perception of the performance of the vehicle.

Figure 7 - Fleets user attitudes by age chart



83% of fleet users in their 20s felt more positive about electric vehicles after the trial, compared with a 25% opinion shift for users in their 60s

6.2 Fleet managers' questionnaires

Fleet managers participating in the trial were issued with questionnaires to assess the affect that the different operational requirements of an electric vehicle had on fleet performance and the attitudes of the organisations' managers.

Key findings

- **Fleet managers' motivations for taking part in the trial were predominantly environmental aspirations and the opportunity to learn about EV integration.**
- **Organisations did not consider installing infrastructure at base or the lack of public charging points to be barriers to the incorporation of electric vehicles into their fleets.**
- **Range and purchase price are the main barriers to fleets integration.**
- **88% of fleet managers felt more positive about incorporating electric vehicles into their fleets after participation in the trial.**

The participating organisations' fleet managers were invited to give feedback on how they perceived the advantages and disadvantages of running electric vehicles in their fleet after their trial experience. An 80% questionnaire return rate was achieved from the ten organisations participating in the trial. In the questionnaire, fleet managers were asked the following questions and were allowed to highlight the pre-defined answers which were most relevant to their experience.

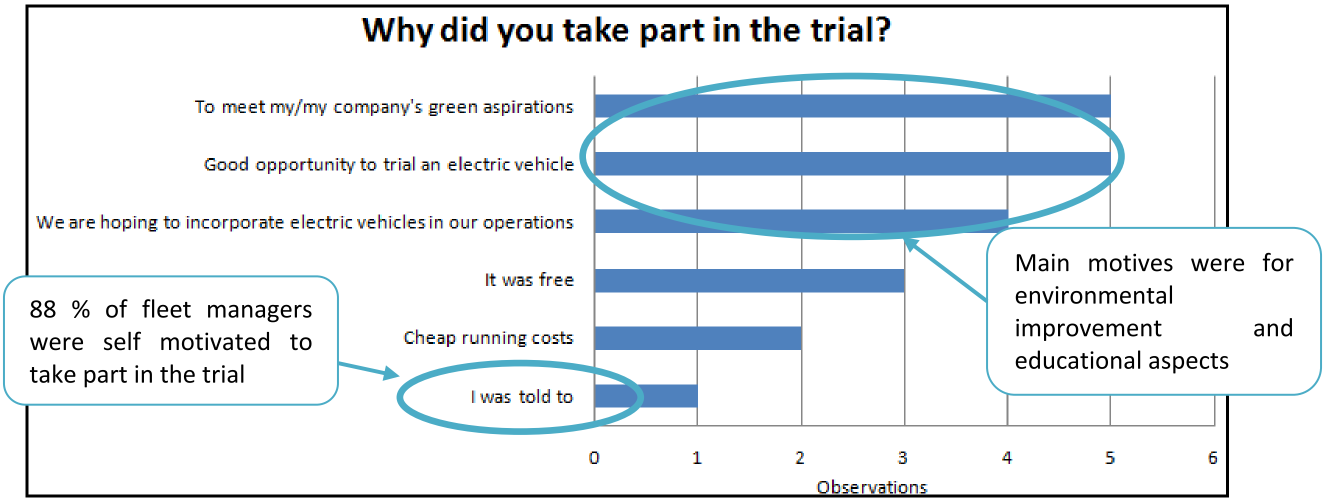
- What were your main motives for taking part in the smart move trial?
- What significant adjustments have you had to make to your fleet operations to accommodate the electric smart(s)?
- How did your organisation benefit most from operating the EVs?
- What were the main disadvantages of using the EVs?
- What would be the main disadvantages of you incorporating electric vehicles into your fleet?
- Has your time operating an EV affected your opinion of electric vehicles?

The answers received from these questions can be summarised under three broad headings as detailed below.

6.2.1 Motivation and advantages

The organisations main motives for taking part were to take advantage of the opportunity to trial electric vehicles and to satisfy the organisations green aspirations. 50% of organisations were already hoping to incorporate electric vehicles into their fleets as part of their long term transport strategy.

Figure 8 - Fleet managers' trial motives chart



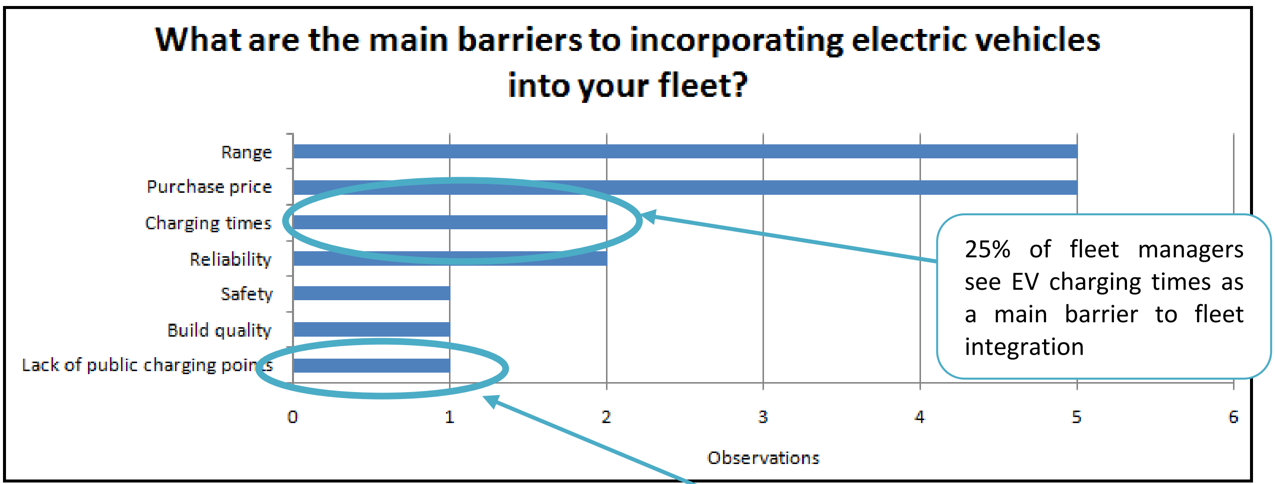
Fleet managers rated the advantages of taking part in the trial similarly to their original motivations and aspirations before trial commencement. This shows that the trial was designed and managed effectively and helped organisations gain the experience they required to make more informed decisions about EV fleet integration.

6.2.2 Barriers and disadvantages

The main adjustments managers had to make to the operation of their fleet was to manage the type and number of journeys, mainly due to range restrictions but also to more specific attributes of the smart which are passenger and storage restrictions.

88% of fleet managers thought that installing infrastructure at base and the lack of public charging infrastructure was a not a main barrier to incorporating electric vehicles into their fleets.

Figure 9 - Fleet managers' barriers to implementation chart

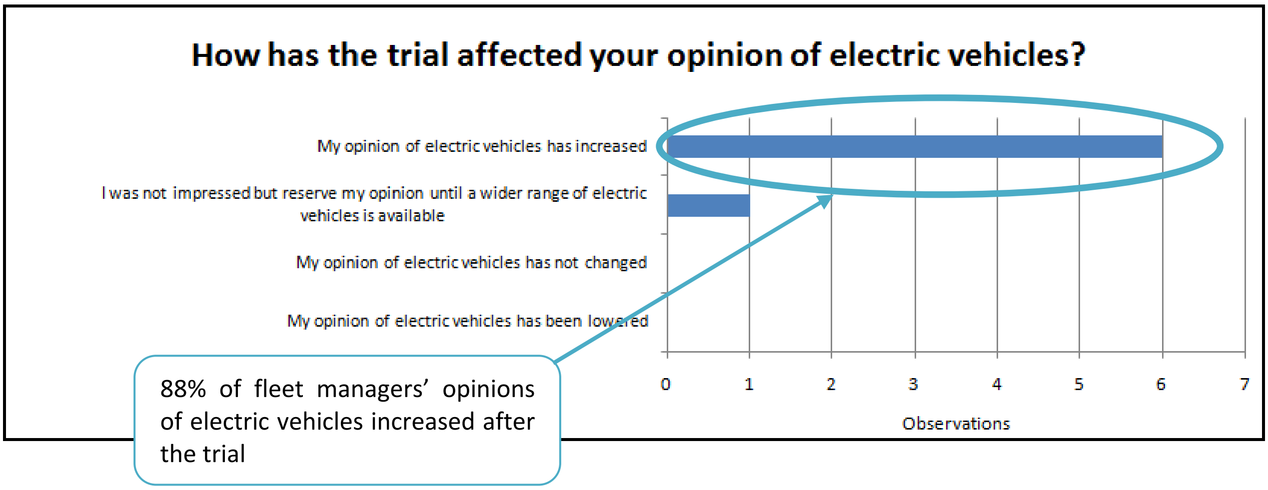


Purchase price and range were stated as key barriers to implementation for organisations using electric vehicles.

6.2.3 Opinions of electric vehicles

As observed in the fleet user data, the fleet managers' opinions of electric vehicles were also increased through participation in the trial. This key aspect shows that despite the restrictions on electric vehicles to suitable tasks and the additional management required, the fleet managers saw benefit to their organisation and fleet through incorporation of electric vehicles.

Figure 10 - Fleet managers' opinions chart



6.3 Public drive events

Three public drive events took place during the trial. Here test drives were freely available to members of the public who could either pre-book a drive or turn up without prior arrangement during an event day.

Key findings

- **72% of test drivers said they would use an electric vehicle as their regular car after their test drive compared with just 47% before the test drive.**
- **82% of the general public who test drove the smart would consider owning an electric vehicle compared with 56% from a captive test drive audience of conference delegates.**
- **The younger age groups (20s and 30s) had lower expectations from the vehicles. The largest positive shift in opinion after the test drive existed for users in their 20s.**
- **During test drives the electric vehicle exceeded the general public's expectations on all monitored performance aspects.**

Table 7 below shows attendance and basic statistics from the test drives.

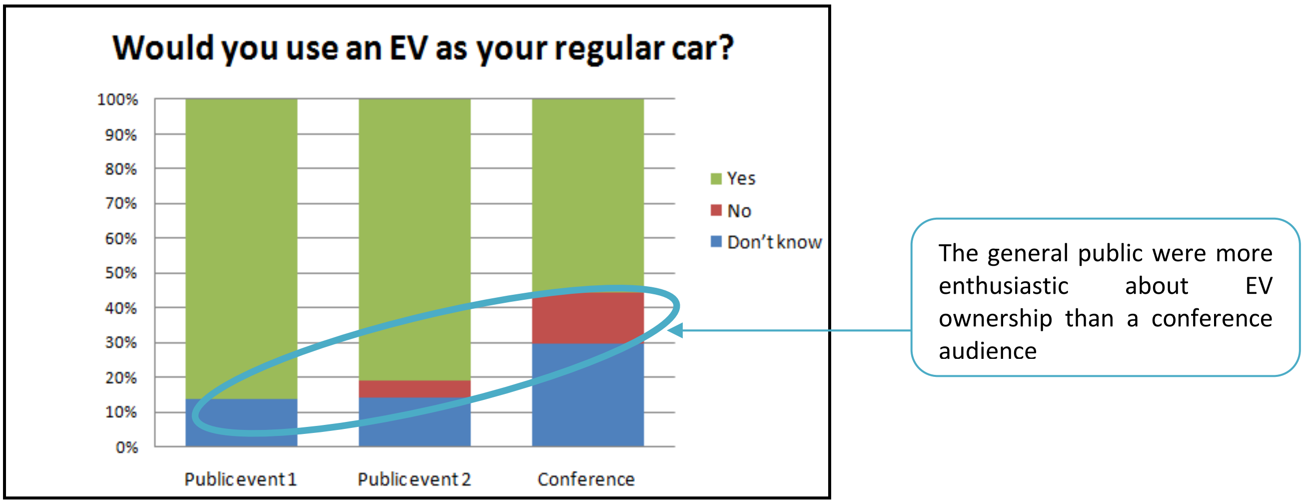
Table 7 - Public drive event statistics			
Event	**Number of drivers**	**Test drive route distance (km)**	**Audience**
Public event 1	22	5.8	General public
Public event 2	20	6.0	General public
Conference	27	6.0	Sustainable travel group

The electric vehicle test drives were provided at locations across Gateshead. The majority of drivers were passers-by who had little or no knowledge and experience of electric vehicles, the associated costs or charging procedures.

6.3.1 Perception on EV ownership

Test drivers were asked if they would use an EV as their regular car after their test drive experience. The resultant answers are shown in Figure 11 below and grouped by event location.

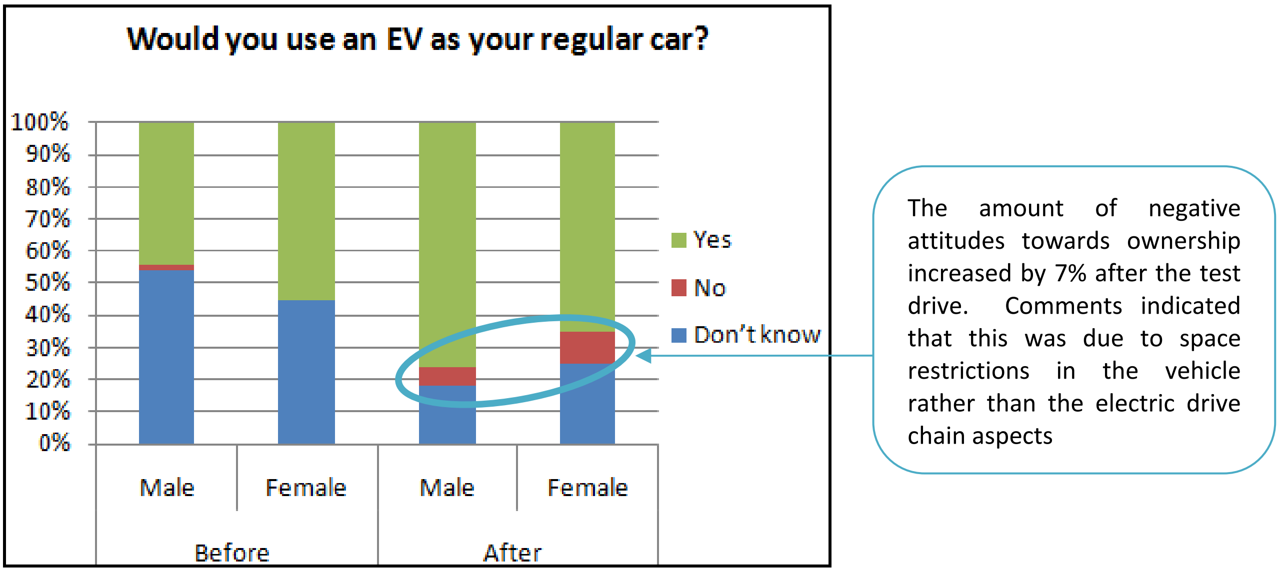
Figure 11 - Public test drive EV ownership perception chart



One drive event took place during the ACT Travelwise annual conference. ACT Travelwise is a network for organisations working to promote sustainable travel and the test drivers were exclusively conference attendees. There is a clear difference in opinion on EV ownership where conference attendees had a more reserved opinion before the test drive and a decreased positive shift in opinion afterwards when compared with the general public. This may be because they are more aware of barriers to implementation such as cost and range of EVs.

In terms of differing attitude by gender, Figure 12 shows that the male population were more reserved in its opinions on EV ownership before the test drive and the data shows that after the test drive there was a larger positive shift on EV ownership aspirations.

Figure 12- Public test drive EV ownership perception by gender chart



The male population were influenced most by the test drive and showed a 43% shift in positive opinion compared with a 10% shift in female opinion.

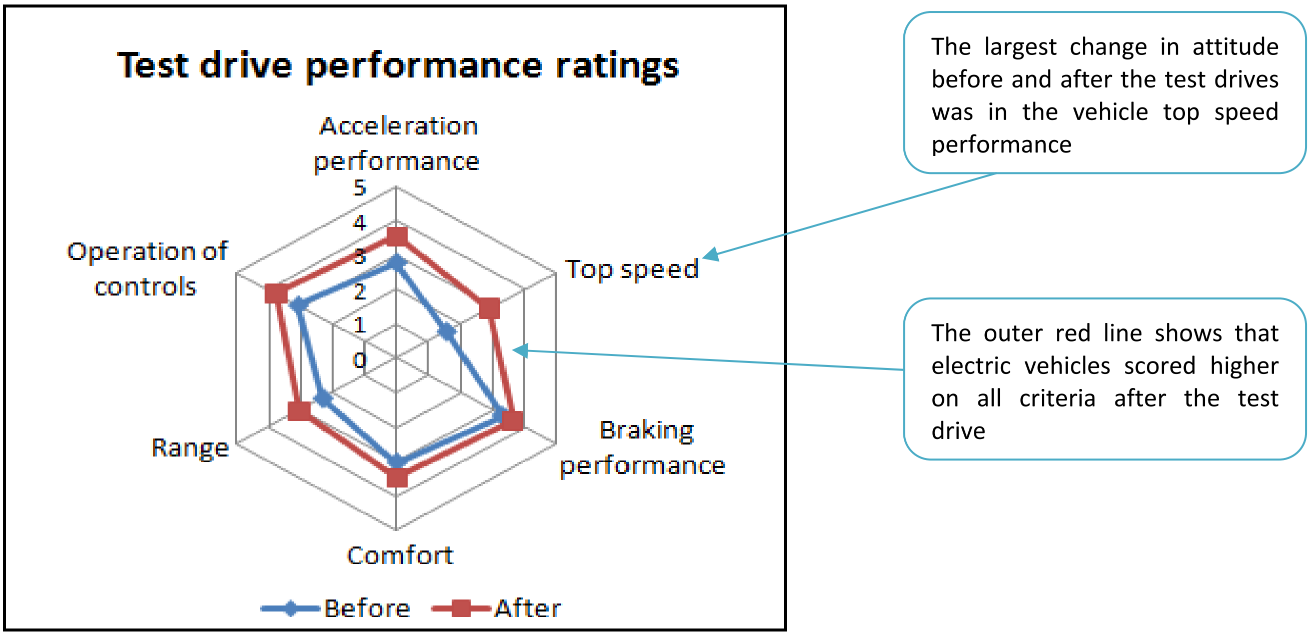
6.3.2 Perception on EV performance

Test drivers rated their expectation of the performance of the electric vehicles before the drive and then rated against the same criteria after the test drive. This gave an interesting snapshot of the expectation versus actual performance of the electric vehicles.

The test drivers were asked to benchmark the performance rating against performance of a similar class fossil fuelled vehicle. The ratings were simply 'worse than', 'about the same' or 'better than' which were given a score of 1, 3 and 5 respectively to allow quantitative analysis. The results of this analysis are shown in Figure 13 below which shows that the vehicle out performed against expectations on all performance aspects.

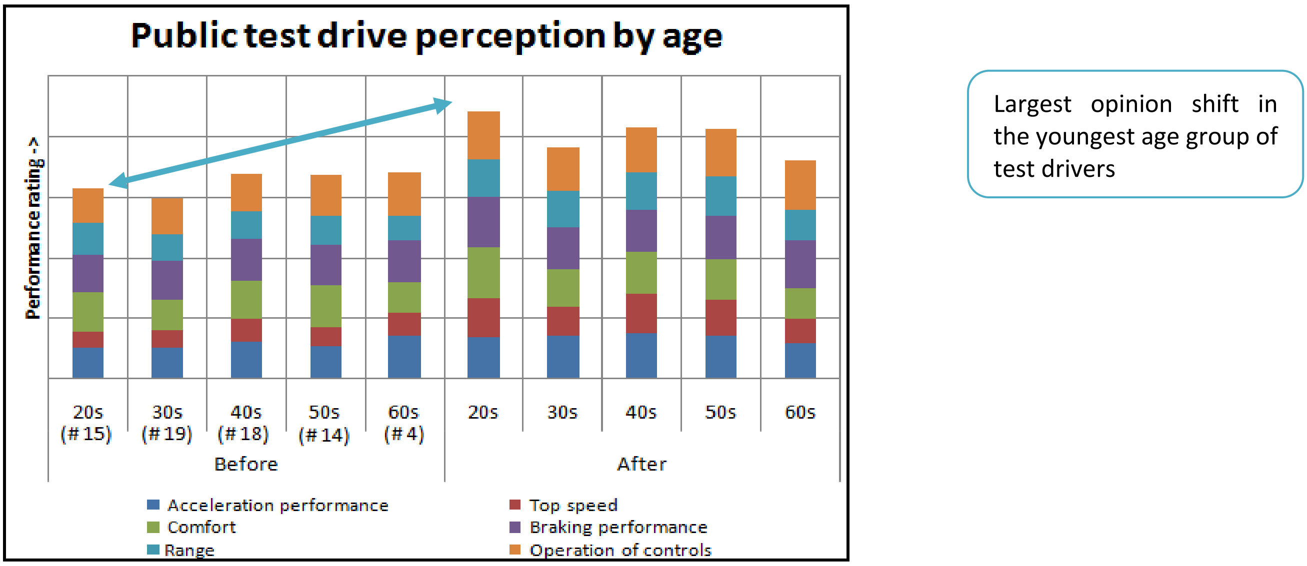
The largest change in attitude was concerning the top speed performance of the EV.

Figure 13 - Test drive performance ratings



The deviation in answers received suggests that the drivers disagreed most on the range and the acceleration performance of the vehicle. Figure 14 below shows the average performance rating in each category has been stacked by test drivers' age group. Here an overall rating of the vehicle performance can be seen. The younger generations are more cautious about owning an EV before the test drive. After the test drive there is no clear pattern in attitude by age except that the largest change in opinion towards EV ownership is observed in the 20s ages group.

Figure 14 - Test drive perception by age



6.4 Qualitative data summary and discussion

Table 8 below summaries the key findings in the qualitative data analysis.

Table 8 – Qualitative data key findings summary table		
Number of different drivers	**Questionnaire returns**	**Participating organisations**
264	190	10

Fleet user key points

- 58% of fleet users felt more positive about electric vehicles after taking part in the trial.
- Users in their 20s experience the highest opinion shift of all the age groups with 83% of users feeling more positive about electric vehicles after their trial experience.
- Users rated the overall performance of the EV as 'Good'. Most variation in answers was observed in the noise category. This represented a split in opinions between the environmental improvements and the public safety concerns associated with low noise emission vehicles.
- Predominantly return-to-base charging at work was employed through the trial, users rated their charging experience as 'Good', finding vehicle charging easy, safe and reliable.
- Public sector fleets scored the recharging aspects 9% higher than private sector fleets (this may be because 50% of the public sector fleets had access to dedicated recharging infrastructure) and rated charging facility availability and safety 20% and 13% higher than private fleets respectively.
- 95% of users found the vehicles always or normally had enough charge for their intended journey although 34% of users had experienced moments where they felt the vehicle may not have had enough charge for their intended journey. 73% of users in fleets with access to dedicated recharging infrastructure found the vehicle on charge (topping-up) before use compared to 42% of users who operated in fleet without dedicated infrastructure.

Fleet managers key points

- Fleet managers' motivations for taking part in the trial were predominantly environmental aspirations and the opportunity for learning about EV integration.
- Organisations did not consider installing infrastructure at base or the lack of public charging points to be barriers to the incorporation of electric vehicles in to their fleets.
- Range and purchase price are the main barriers to fleet integration.
- 88% of fleet managers felt more positive about incorporating electric vehicles into their fleets after participation in the trial.

Public drive event key points

- 72% of test drivers said they would use an electric vehicle as their regular car after their test drive compared with just 47% before the test drive.
- 82% of the general public who test drove the EV would consider owning an electric vehicle compared with 56% from a captive test drive audience.
- The younger age groups (20s and 30s) had lower expectations from the vehicles. The largest positive shift in opinion after the test drive existed for users in their 20s.
- During test drives the electric vehicle exceeded the general public's expectations on all monitored performance aspects.

The key points in the table above support the hypothesis that fleets are suitable early adopters for electric vehicles. The general public test drivers and the fleet users rated the performance aspects of the vehicles as 'Good'. The fleet users also found charging easy, safe and reliable. The barriers of cost and range would be easier to absorb in a fleet context than for an individual. Fleets can more easily maximise the number of journeys the vehicles do and have a wider pool of total journeys to be able to keep daily mileage high whilst vehicles undergo appropriate length trips. Considering this, the overall cost of ownership (pence per mile) is likely to be lower for fleets.

The very positive attitudes towards EVs in this analysis could be a reflection on the voluntary nature of involvement in all aspects of the trial, and hence the opinions expressed in the analysis will be positively skewed. This observation is worth noting but does not distract from the key findings which is that EVs can be successfully integrated into fleet scenarios. The fleet managers, who oversaw the integration of the loan vehicles for up to 4 weeks and also have the responsibility for operational excellence and fit for purpose aspects of the organisations fleet, had high levels of enthusiasm and felt more positive about electric vehicles after the loan period.

The public drive data was a snap shot of EV perception before and after a test drive. Here it was observed that the EV outperformed expectation on all criteria which shows that there is a need for wider dissemination on advances that electric vehicle technology has made in recent years.

7 Quantitative data analysis

This section presents the results of the analysis on quantitative data recovered during the trial. This comprises the data recorded from the telemetry system and data logged from the electric vehicle CAN bus. This data allows a review of the actual performance and usage patterns of the vehicles during the trial.

The summary of this data can be feed back to fleet managers to provide information on the actual range and carbon emission performance of the vehicles to complement the practical integration aspects learnt through participation in the trial.

The following data analysis covers approximately 100 trial journeys taking place during January and February 2010. It is worth noting that this is not a complete data set for the smart move trial and hence the presented analysis should be seen as representative rather than a complete analysis of the six month trial period.

The quantitative data analysis put forward in this report is a brief overview of some of the technical issues effecting vehicle efficiency and range during the smart move trial. The full analysis of this and other electric vehicle research and studies by Cenex and its partners will be disseminated at an event during the summer of 2010. To register interest in attending this event please email technical@cenex.co.uk

7.1 Smart range and CO_2 emissions

The range from an electric vehicle is stated as the number of kms available from a fully charged battery. An electric vehicle does not inherently emit CO_2 during use, but the electricity used to recharge an EV is normally produced from CO_2 emitting power stations and hence, the emissions from the electricity generator/s are associated with the vehicles use.

Key findings

- **The average range achievable from the EVs was 72.4 km emitting 81.4 g CO_2/km when recharged with UK average grid mix electricity.**
- **If charged with lower carbon sources of electricity, the vehicles achieve average emissions of 45.0 g CO_2/km from CHP and 0 g CO_2/km from renewable electricity.**
- **Range varied up to +/- 40 km dependent on operating conditions.**

Extrapolated range is determined by the energy efficiency, in km travelled per battery percent state of charge (SoC) used, of an individual journey which is then used to calculate the theoretical battery range achievable. The average extrapolated range from the trial was 72.4 km.

For the smart move trial, the CO_2 emissions from the electric vehicles have been calculated based on the carbon intensity of the UK's electricity grid generation mix. The Department for Environment, Food and Rural Affairs (Defra) produce electricity emission factors to help businesses convert existing energy usage into CO_2 equivalent emissions. The emission factors relating to different generation types are detailed in Table 9 below together with their effect on the average emissions of the EVs during the trial.

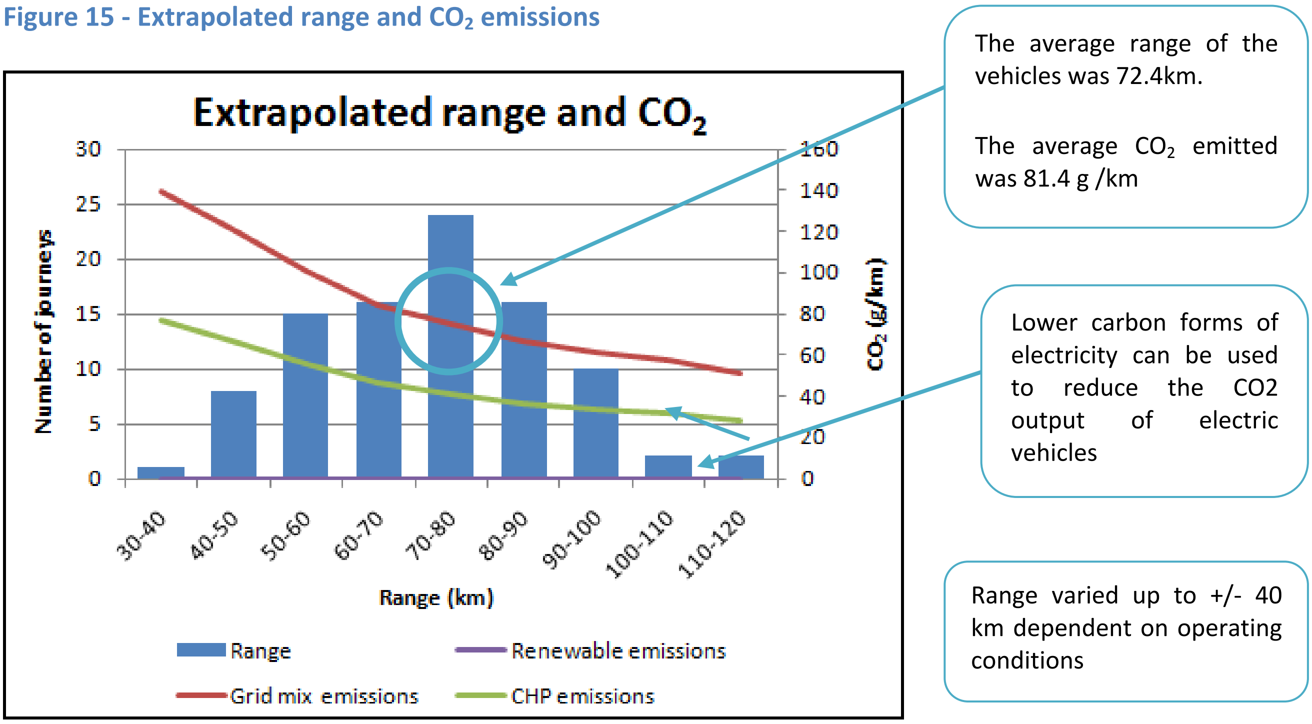
Table 9 - Electricity generation source affect on vehicle emissions

Electricity source	Defra 2009 emission factors[1] (g CO2 / kWh electricity)	Average EV emissions (g CO2 / km)
UK national grid mix	544.2	81.4
CHP generation	301.1	45.0
Renewable electricity	0	0

[1] Defra 2009 emission figures http://www.defra.gov.uk/environment/business/reporting/pdf/20090928-guidelines-ghg-conversion-factors.pdf

Figure 15 below shows the variation in extrapolated range from the EVs and the CO_2 emissions based on the three electricity generation sources detailed in the table above.

Figure 15 - Extrapolated range and CO_2 emissions



The range and therefore the CO_2 emissions of the vehicles varied significantly depending on the operating conditions of the vehicle. It should be noted that the CO_2 emissions presented in this report are derived from the power delivered to and from the vehicle battery and do not account for charging and battery efficiency.

7.2 Sources of variation

Some of the reasons for the variation in range and emission performance from the EVs are explored in this section. Although this analysis is performed exclusively on the smart electric car data, the sources of variation are characteristic of electric vehicles in general.

Key findings

- **The power recovered through regenerative braking was 11.3% of the motoring power during the trial. The regeneration rate varied from 3 to 29% depending on journey driving conditions.**
- **High journey efficiencies occur when journey regeneration rates are low suggesting that the efficiency of vehicle energy recovery is low and greater potential exists to reduce energy consumption through more progressive and predictive driving.**

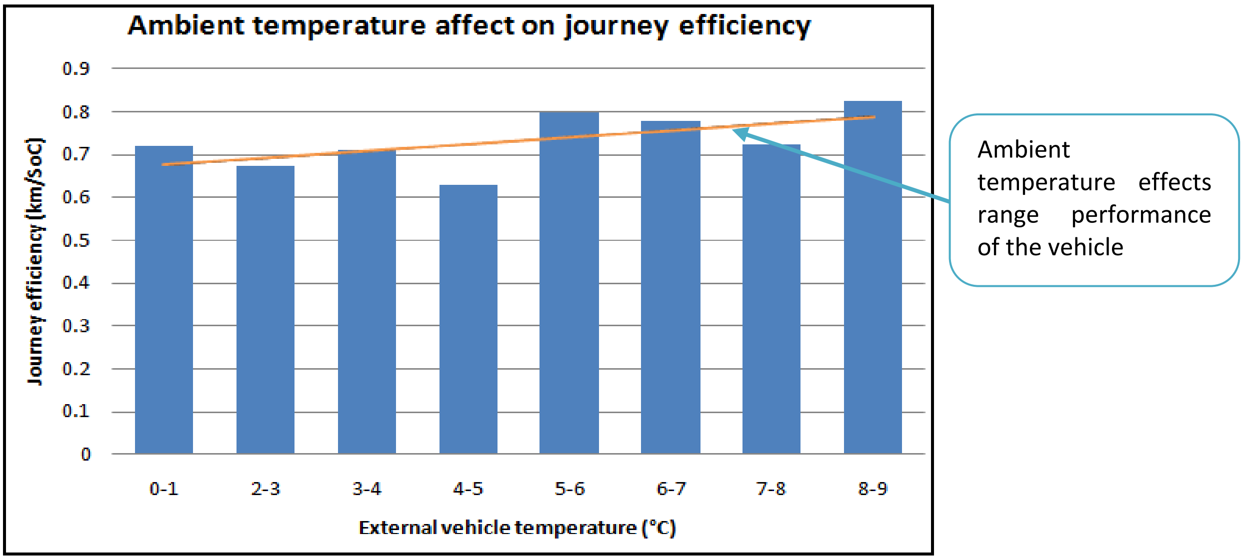
The variation in vehicle range and CO_2 performance between the journeys can be accounted for through a number of factors including hotel loads (parasitic energy demands on a vehicle not directly contributing to distance), driving style, terrain, acceleration/deceleration rates and journey speed.

The charts in this section show range performance in terms of km per battery state of charge used. The state of charge of the battery is expressed as a percentage; hence extrapolated range can be calculated through multiplying the journey efficiency (km/SoC) by 100.

7.2.1 Ambient temperature effect on range and CO_2

Figure 16 below shows the affect of ambient temperature on range and CO_2 performance of the journeys.

Figure 16 - Journey efficiency by ambient temperature chart



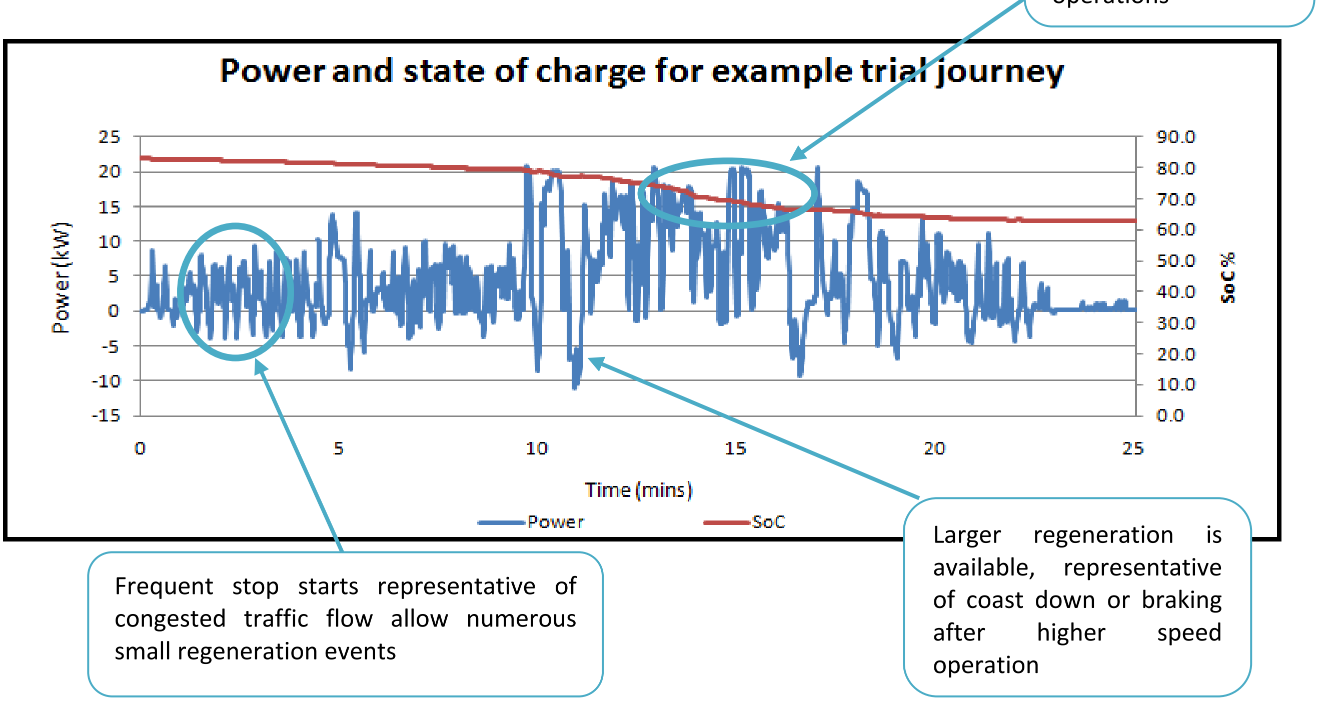
The trend in energy consumption with temperature can be explained though a number of factors.

- As temperature decreases it is likely that there is a higher demand from hotel loads. The cabin heater will have a significant effect on range as the unit comprises a 2 kW heating element where continual use would require approximately 13% of the total battery energy available.
- The smart car utilises a battery technology which must be maintained at a temperature of ~300°C, hence the differential between ambient temperature and battery temperature must be compensated for by diverting additional energy to battery heating.

7.2.2 Regenerative braking analysis

The smart has regenerative power capabilities. While the vehicle is in coast down or under braking the motor is used as a generator and the vehicle momentum is used to feed electrical charge into the battery. The amount of regenerative braking energy captured in a journey will be dependent on the potential energy of the vehicle whilst under braking, frequency of braking and deceleration rates. Figure 17 below shows the power and battery state of charge behaviour from a typical 25 minute journey during the trial. When the vehicle is motoring the energy value is positive and while the vehicle is in a state of regeneration the energy value is negative.

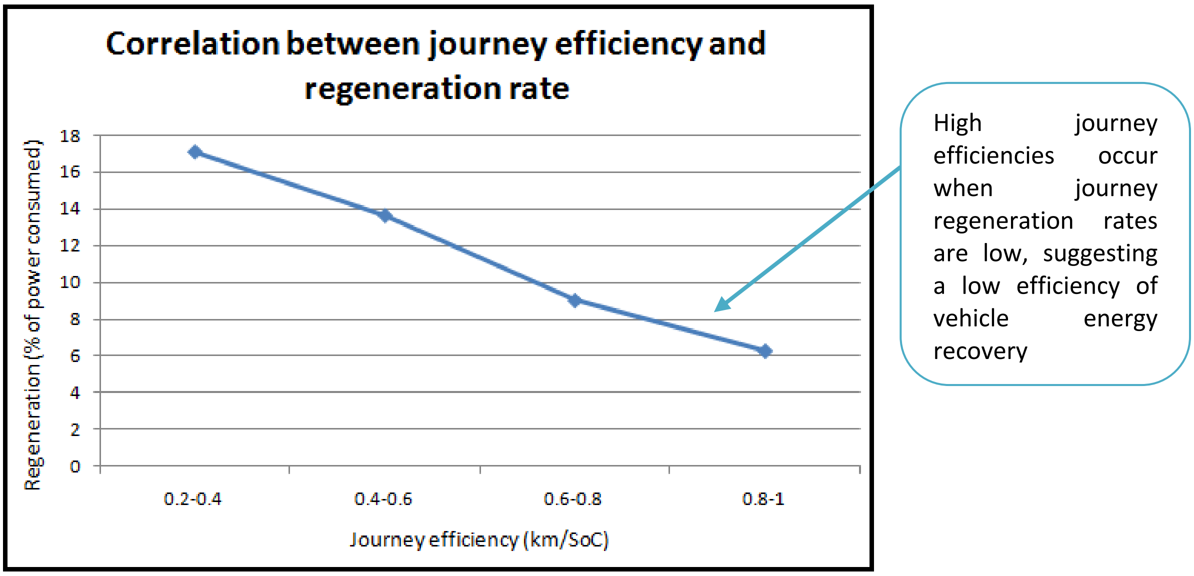
Figure 17 - Power and state of charge run chart



The journey detailed above consumed 2.13 kWh for motoring and regenerated 0.210 kWh, giving a regeneration rate of 9% for the trip. The total regeneration achieved in all the logged journeys over the trial period was 11.3% and this ranged from 3 to 29% depending on journey driving conditions.

The power available from regenerative braking is a fraction of that consumed through vehicle acceleration and the conservation of momentum. Figure 18 below illustrates this by showing the relationship between driving efficiency and regenerative braking power.

Figure 18 - Regeneration rate by journey efficiency chart



This chart above suggests that the most efficient journeys involved fewer braking moments; hence less energy is lost through friction braking, coast down and energy conversion.

Braking is obviously an essential part of driving but an opportunity to increase range exists through modification of driving style to reduce wasted energy, primarily through more progressive and predictive driving reducing excessive acceleration and any unnecessary braking and secondly through educating users of the most effective ways of maximising on regeneration rates through driving style.

7.3 Journey length

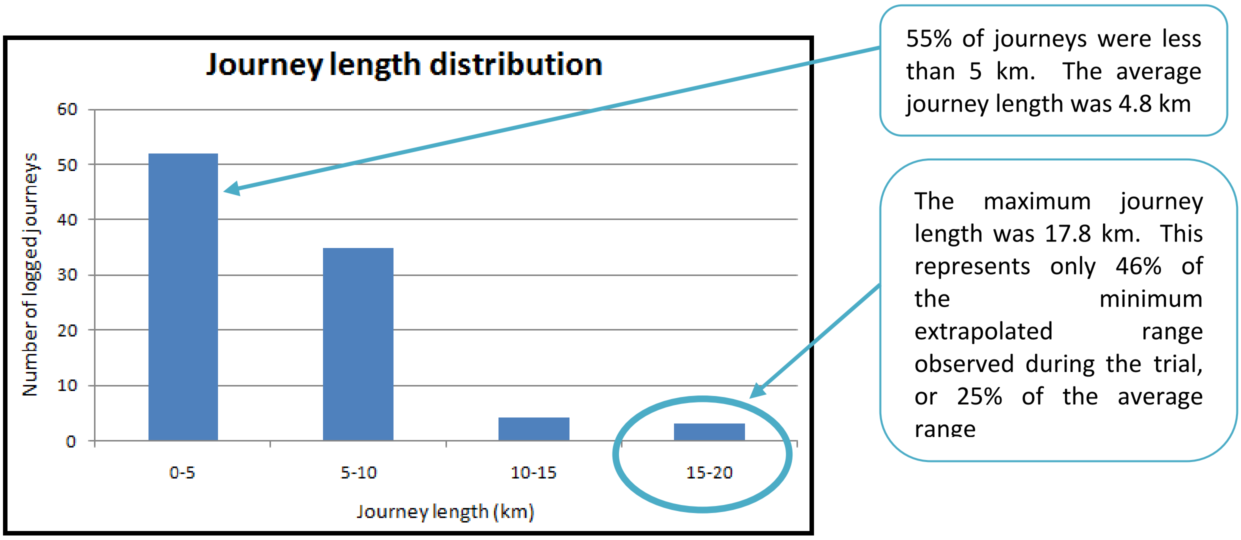
This section further describes how the vehicles were used and reports on the distribution of journey lengths during the trial. The section then continues to report on a number of observations made from the data while investigating why the EVs were deployed for mostly low mileage journeys.

Key findings from the 100 trips observed

- **The Average journey length was 4.8 km.**
- **The maximum journey length was 17.8 km. This represents only 46% of the minimum extrapolated range observed during the trial and 25% of the average extrapolated range.**
- **93% of journeys were started with above 50% battery SoC.**
- **Users began to modify driving style when SoC approached 50%.**
- **Users did not use the available range of the vehicle.**

Figure 19 below shows the distribution of journey lengths for the logged data. Only a small amount of the available range was used, however a number of these journeys would require a repeat journey of equal length for a back-to-base charging operation.

Figure 19 - Journey length frequency chart



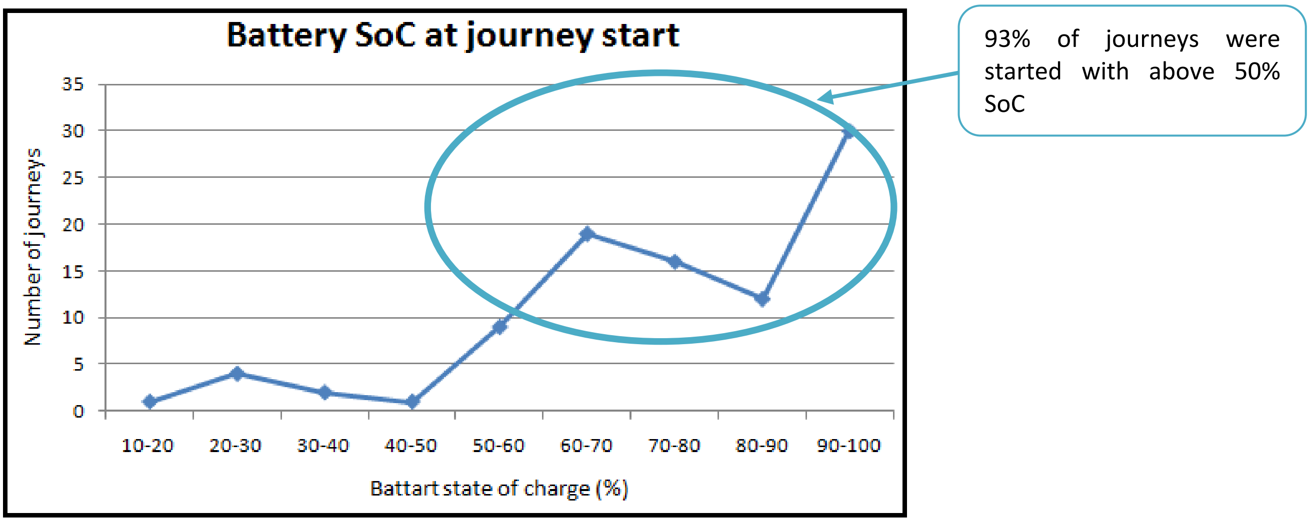
Organisations were selected for trial involvement based on, amongst other criteria, the ability to achieve a wide variety of vehicle operating regimes, including an equal distribution of short and long journeys. The chart above shows that in practice users restricted the use of the vehicle to their own comfort level once the EV was on site.

7.3.1 Range anxiety

A contributor to the perceived available range of electric vehicles is the range anxiety which users undergo when considering the suitability of using an EV for a potential journey. The extrapolated average range during the trial was 72.4 km. This assumes that the battery is used to capacity during a journey. In reality, and depending on a driver's perception a personal level of comfort will exist in the degree a user is willing to discharge the vehicle battery. Range anxiety is particularly relevant in the current climate where public recharging infrastructure volumes are low.

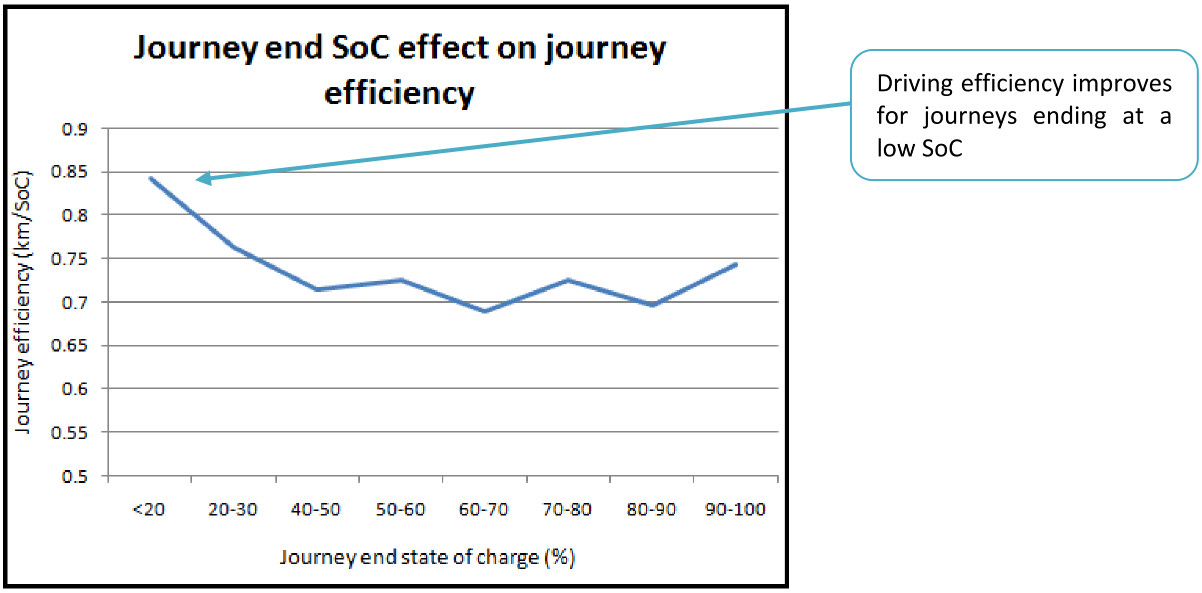
Figure 20 below shows the battery state of charge at the beginning of the journeys. Only 7% of journeys were undertaken when the battery was showing less than 50% state of charge. Even at 50% SoC, using the minimum theoretical range experience during the trial all the journeys could be completed. The range variation detailed in section 7.1 above obviously adds uncertainty to a user's evaluation of whether enough power is available to accomplish a journey within a comfortable safety margin.

Figure 20 - Battery state of charge frequency chart



Range anxiety can be further demonstrated through Figure 21 below. This shows that there is a relationship between journey efficiency and the state of charge of the battery at the end of the journey. The trend suggests that users begin to modify their driving style as the vehicle state of charge reduces to less than 50%.

Figure 21 - Journey efficiency by battery state of charge



7.4 Quantitative data summary and discussion

Table 10 below summarises the key points from the quantitative data analysis.

Table 10 - Quantitative data key findings summary table
Range, CO_2 emissions and regeneration
• The average range achievable from the EV was 72.4 km emitting 81.4 g CO_2/km when recharged with UK average grid mix electricity. • If charged with lower carbon sources of electricity, the vehicle can achieve average emissions of 45.0 g CO_2/km from CHP and 0 g CO_2/km from renewable electricity. • The range varied up to +/- 40 km dependent on operating conditions. • The power recovered through regenerative braking was 11.3% of the motoring power during the trial. The regeneration rate varied from 3 to 29% depending on journey driving conditions. • High journey efficiencies occur when journey regeneration rates are low suggesting that the efficiency of vehicle energy recovery is low and greater potential exists to reduce energy consumption through more progressive and predictive driving.
Journey length and range anxiety
• The average journey length was 4.8 km. • The maximum journey length was 17.8 km. This represents only 46% of the minimum extrapolated range observed during the trial and 25% of the average extrapolated range. • 93% of journeys are started with above 50% battery SoC. • Users begin to modify their driving style when SoC approaches 50%. • Users did not use the available range of the vehicle.

It is shown that the CO_2 emissions from the electric vehicles can be significantly reduced or eliminated when lower carbon or alternative energy sources are used. As the UK government meets its targets to decarbonise the national electricity mix, the CO_2 emissions from electricity will reduce. This decarbonisation of the electricity network will coincide with advancements and mass market introduction of electric vehicles offering an inherently low carbon future for EVs.

The study on the amount of regenerative braking available and its affect on journey efficiency highlights the opportunity to increase range through modification of driving style to reduce wasted energy, primarily through more progressive and predictive driving, reducing excessive acceleration and any unnecessary braking, and secondly through educating users of the most effective ways of maximising regeneration rates.

The journey length and range anxiety analysis showed that the electric vehicles were not being deployed to their full capabilities during the trial. This may be due to the short duration of the loans (one to four weeks) where users require time to gain confidence in the range performance of the vehicles. This confidence building stage is undesirable in terms of efficient deployment and acceptance of EVs and highlights a need for more sophisticated on board range prediction aids within electric vehicles especially as the number of electric vehicles available to the market increases.

8 Trial conclusions

The trial has shown that strong potential exists for fleet operators to be early adopters of electric vehicles. Fleet users rate the performance of modern electrical vehicles as 'Good' and found charging aspects easy, safe and reliable. Fleet managers have successfully integrated the vehicles into their fleets for a short trial and gained confidence that EVs can realistically form part of their transport fleet.

A reason for the success of the trial is that, due to the return–to-base operation of fleets, the lack of public infrastructure is not seen as a barrier to the integration of EVs. Organisations with dedicated recharging infrastructure rated the charging experience higher than those without. They managed the charging of the vehicles more effectively thereby allowing more journey confidence due to a higher journey battery state of charge.

Fleet managers highlighted the main barriers of EV integration as purchase price and limited range, although the quantitative data from vehicle telemetry shows that users are over cautious when planning journeys. This was demonstrated in the trial data where the maximum journey length undertaken was only 25% of the theoretical average range. Range anxiety effects were significant throughout the trial with 93% of journeys commencing with over 50% SoC and data suggests that users modified their driving style when journey SoC reduces below 50%. The under-utilisation of range is undesirable in terms of efficient deployment and acceptance of EVs and highlights a need for more sophisticated on board range prediction aids within electric vehicles especially as the number of electric vehicles available to the market increases.

During the public test drives it was observed that the EVs outperformed expectation on all criteria which shows that public awareness of the advances in electric vehicle technology in recent years is low. Test drivers and fleet users in the 20 to 30 year age group experienced the highest opinion shift of all the age groups in favour of EV ownership which may be an early identification of a potential target market relevant to the deployment of commercially available electric vehicles.

The average range achievable from the electric vehicles was 72.4 km emitting 81.4 g CO_2/km when recharged with UK average grid mix electricity. If charged with lower carbon sources of electricity, the vehicles achieve average emissions of 45.0 g CO_2/km from CHP and 0 g CO_2/km from renewable electricity. As the UK government meets its targets to decarbonise the national electricity mix, the CO_2 emissions from electricity will reduce. This decarbonisation of the electricity network will coincide with advancements and mass market introduction of electric vehicles offering an inherently low carbon future for EVs. The variation in range was +/- 40 km depending on operating conditions.

Fleet managers rated the advantages of taking part in the trial similarly to their original motivations and aspirations before trial commencement. This shows that the trial was designed and managed effectively and helped organisations gain the experience they required to make more informed decisions about EV fleet integration.

9 Next steps

Cenex intends to further deploy electric vehicles on planned trials throughout 2010 and beyond thereby increasing the quantity and diversity of vehicle technology and types assessed. This will build on the smart move trial work and further assist organisations to decarbonise fleets while making informed choices on the most operationally suitable vehicles available.

The results of further analysis on the smart move telemetry data will be reported along with ongoing electric vehicle research and studies by Cenex and it's partners during a dissemination event in summer 2010.

To register interest in attending this event or with queries relating to the smart move trial and other Cenex vehicle trials and capabilities please email technical@cenex.co.uk

Cenex

Holywell Park

Loughborough University

Ashby Road

Leicestershire

LE11 3TU

telephone 01509 635 750

facsimile 01509 635 751

www.cenex.co.uk