ELECTRIC VEHICLES

AN **INTERVIEW STUDY** INVESTIGATING THE PHENOMENON OF RANGE ANXIETY

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Executive Summary

A qualitative interview study investigating the existence of range anxiety

The introduction of Electrical Vehicles (EVs) presents new challenges for drivers. In particular, range anxiety has been identified as one of the main obstacles to the success of EVs.

This report details research activities carried out by Lindholmen Science Park as part of work package 5000 within the ELVIRE project during the period: April 2011- December 2011. It describes the interview study investigating the phenomenon of range anxiety.

The interview study targets EV drivers having access to an EV via ownership/ private loan/work/research projects in Sweden. This allows for a study independent of EV brand, hence going above and beyond what has previously been published regarding range anxiety.

The interview study is of qualitative nature (semi-structured questions), involving 8 Swedish EV drivers.

The overall objective of the report is to:

- Demonstrate the EV driver´s view of range anxiety
- Illustrate the effects and causes of range anxiety

To address these objectives, the report details the motivation, procedure, and result of the performed interviews. The goal of the report is to provide the necessary means to conduct further empirical studies, in this case a questionnaire study targeting range anxiety.

The scope of the work is restricted to the experience of the respondents of the study.

Main findings

The 2 reported limited range incidents occurred in the first week of the trial. The drivers connected the incident to the lack of time to become familiar with the behaviour of the EV. This, together with unforeseen incidents and difficulties in understanding the current state of the EV caused the limited range incident. Interestingly, the situation was allowed to evolve because the drivers had identified a strategy to solve the upcoming situation.

Most typically, range anxiety is manifested as an awareness of the current range, to which the drivers adapt [R1-R8] [1]. The drivers utilised coping strategies, and could, that way, exclude the possibility of limited range incidents [R1-R8][1].

In particular, estimated range (especially), together with state-of-charge and the power meter (eco driving) are the most useful dials while driving an EV [R1-R8] [1]. The information is used to increase the awareness of the current situation and to position oneself and ones own actions in in relation with the range. It is also shown that providing information about charging opportunities may have a positive effect on range anxiety [R4-R7] [1].

It should be noted that the findings of this study provide initial indications. These findings will be further verified a questionnaire study.

Quick facts.

Number of Respondents	Statement [1]
1 of 8	Became stranded along the way without power during the first week [R1]
1 of 8	Aborted a journey (stopped along the way) due to low charge during the first week [R7]
4 of 8	Had not heard the expression range anxiety before this study [R6, R8, R7, R4]
4 of 8	Wanted information about possible charge points along the journey [R4-R7]
8 of 8	Stated that range anxiety is not a problem while driving to your known destination [R1-R8]
8 of 8	Argued that more careful planning was required in an EV [R1-R8]
8 of 8	Consciously or unconsciously planed their trip before stepping into the EV [R1-R8]
8 of 8	Stated that range estimation in km is the most important information sources for minimizing range anxiety [R1-R8]
8 of 8	Used a combination of range estimation [R1-R8], power meter [R1, R6-R8] and state of charge [R1-R3] to make sure that they would reach their destination

[1] "R" followed by number= Respondent identification (i.e., Respondent 1 … Respondent nr 8)

Content

1. Introduction

Introducing the terminology, motivation, aim and objectives of the study.

Range anxiety is a term mostly associated to EV in the context of their limited range and underdeveloped infrastructure of charging opportunities (Wellings et al., 2011).

Range anxiety is, in many ways, an intuitive term, defined herein as the perceptions or the experience of drivers regarding the fear of not reaching your destination while driving an EV.

One issue with range anxiety is that there is not a considerable amount of publicly published scientific material investigating the phenomenon. The issue has most often been investigated as part of larger, more general, EV studies, providing a somewhat contradicting description.

A report by Wellings et al., (2011) for instance suggests that range anxiety was reduced as the drivers became accustomed (familiarised) to the EV. Indeed, Taylor (2009) reports that range anxiety, in fact, decreases within just a few weeks of actual use of an EV. However, other drivers have reported that their range anxiety increased as they experienced that they could not trust the feedback they received from the EV (Wellings, et al., 2011). This is also consistent with findings reported by Morton (2011) showing that pre/post trials have revealed that drivers are over-cautions when planning journeys and that range anxiety can, indeed, increase. It should be noted that these studies typically only cover one single brand of EV.

Furthermore, considering the definitions of range anxiety, some refer to the problem of recharging the EVs, that is, the phenomenon may relate to the occurrence of the particular situation. Others mention the available actions needing to be performed when in a situation in which the destination can no longer be reached (Cf. Appendix 1).

A higher-level objective of this report is thus to report on an interview study solely investigating range anxiety, covering different brands of EV and thereby providing further clarifications regarding the subject. More specifically, the objectives of the performed interview study are the following:

- Investigate the experience of range anxiety by EV drivers
- Investigate the cause and effect of range anxiety as experienced by EV drivers

The interview study thus targets only experienced EV drivers participating in different EV projects in Sweden, excluding the opinions of prospective costumers who do not have access to an EV. That is, the focus is on the experience rather than the perception of range anxiety.

The goal of the interview study is thus to provide in-depth knowledge regarding the attributes that form the concept of range anxiety and their relations, independent of the particular brand of EV. Such an independent study, has to our knowledge, not been previously performed.

Figure 1. Illustration of in vehicle system

2. Methodology

Description of the set-up of the study

In terms of methodology, there are different ways of investigating driver experiences of range anxiety. Typically, range anxiety has mostly been studied in pre/post trails (e.g., Brady (2010); Kurani, Turrentine, Sperling, (1996); Golob & Gould, (1998)), capturing both qualitative and quantitative findings. Attitude surveys (e.g., Lane & Potter, 2007) have also been used to identify prospective costumers perceptions regarding range anxiety. The results from those studies indicate that they are effective in capturing the presence of range anxiety. In this study, an interview study is chosen as a method to be able to capture the causes and attributes of range anxiety. It is believed that an interview provides better opportunities than, e.g., a questionnaire to initially explore the underlying attributes of the concept.

Data collection

The interviews are semi-structured in nature and composed according to Breakwell, Hammond and Fife-Schaw (1998), to allow for detailed information regarding the phenomenon of range anxiety. The interviews consisted of explorative questions based on previous research on range anxiety (Wellings et al., 2011; Kurani, Turrentine, Sperling, 1996; Golob & Gould, 1998; Taylor , 2009; Brady, 2010; Sonnenschein, 2010; Weiller, 2011; Wynn & Laefeur, 2009; Botsford & Szczepanek, 2009; Philip & Wiederer 2010; Morton, 2011; Carol, 2010; Franke et al., 2011).

Analysis

The interviews were analysed by the author of this report using grounded theory principles (Strauss & Cobin, 1998) due to the nature of the given data. Grounded theory analysis consists of a series of activities; however, due to the fact that the purpose of the interviews is to inform a questionnaire, only the first stage of the analysis, i.e. "open coding", is chosen. Open coding analyses qualitative data by extracting concepts from the data in which similarities and differences were identified across the respondents. A combination of coding of text passages line-by-line with conceptual codes and a guided search based on Zeidner & Matthews (2011) anxiety taxonomy[2] was performed to characterise the range anxiety phenomenon. Memos were written at several instances of the coding process. A condensed structure of conceptual dimensions and their relations to users' expressions emerged.

In addition, the concepts found in the interview study could be further explored in the planned questionnaire study and, hence, ensure its reliability and validity.

2.1 Material

A template was developed to provide consistency across the interviews; ensuring that all aspects of range anxiety were covered. The questions were open-ended, divided into the following areas (cf. Appendix 2 for interview guide):

- Background (question 1-8)
- General EV concerns (question 9-10)
- The range anxiety concept (question 11-15)
- The range anxiety experience (question 16)
- The range anxiety behaviour (question 17-23)
- Improvements (question 24-27)
- Additional information (question 28)

2.2 Pilot interviews

In this study, a total of four pilot interviews were performed. The first pilot interview (P1) was performed via telephone. This interview was later excluded from the results due to technical problems with the recording of the interview. This interview resulted in changes to procedure due to technical problems with the recording device.

The three remaining pilot interviews (R1-R3) involved participants from the project

[2] (a) the anxiety producing stimuli, i.e., the situation as such, (b) the response channel and reaction to the anxiety, (c) the frequency and intensity of anxiety, (d) the styles of coping with the anxiety.

management team of different EV trails/projects currently running during the test period. The interviews were performed at the respondents work. These pilot interviews resulted in minor changes to the questions. In particular, the questions were changed in nature to capture aspects of range anxiety even though the participant may not have experienced a situation in which he/she believed that he/she experienced range anxiety.

The questions used for the pilot interview were initially analysed to see the effect of the chosen questions, and later added to the final result of the study as no major changes in procedure occurred.

2.3 Participants

In total, 8 people participated in the interview study (3 pilot respondents + 5 main respondents). The participants were identified via the contacts provided by Test Site Sweden, Lindholmen Science Park. The selection of the respondents was constrained to the EV trails/projects currently running during the test period (May 2011 - September 2011). The contact person at the respective site (project/EV trail) did the selection of the individual respondents based on the following criteria:

- The respondent have had experienced the EV during a longer time period (over 3 weeks)
- The respondents represents different trails/projects
- The respondents represents experiences of different EV brands

These requirements resulted in a variation of context of use, ranging from private households to company pool vehicles (cf. Table 1). Implicitly, it also resulted in the participation of one female and seven males.

Details of the respondents

All but one, were highly experienced drivers having access to a gasoline car on a daily basis. The participants' experience of EV specific, ranged between 3 weeks and 2 years. All participants expressed a high interest in environmental aspects. Also, a particular interest in new (future) emerging technologies was identified. To be noted, none of the participants had access to an on-board navigation system.

2.4 Procedure

The contacts at Test Site Sweden were used to find participants to the study. Initial email contacts were established with prospective participants, and followed up by a short introductory phone call in which the interview session could be planned. The interview sessions were performed at a location chosen by the participant. During the interview, the participants were provided with an introduction explaining the goal, and management of the results (e.g., the anonymity). The interview followed an interview guide (cf. Section 2.3 & Appendix 2). The interviews were recorded using the iPhone application iProRecorder, took about 40-60 minutes, and were performed in Swedish (i.e., the mother tong of the participants).

Table. 1. Overview of participants of the study *

Resp.	Gender	Age	EV brand	Exposure	Context of use (loan schema)
P1*	Female	≈ 50	Fiat500Ev	3 weeks	Personal loan: private household
R1	Male	≈ 50	Fiat500Ev	4 weeks	Personal loan: private household
R2	Female	≈ 30	Citroen C1, Peugeot iOn Toyota	3 weeks	Personal loan: private household
R3	Male	≈ 50	Citroen C1 Peugeot iOn	3 weeks	Car pool: company car
R4	Male	≈ 40	Mutchubishi C zero	8 weeks	Car pool: company car
R5	Male	≈40	Tesla, Peogot iOn, Mitchubishi C Zero	2 years	Car pool: company car
R6	Male	≈ 30	Peugeot	12 weeks	Research project: private household
R7	Male	≈ 30	Peugeot	12 weeks	Research project: private household
R8	Male	≈ 30	Peugeot	10 weeks	Research project: private household

*None of the EV had an inbuilt navigation system. Two of the company pool cars had access to a separate navigation unit..

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3. Results and Analysis

Elaboration on range anxiety attributes and its relations

It should be noted that the interviews are presented without the corresponding quotes as the transcripts are in Swedish; instead 'Respondent ID' (R) and 'transcript sentence line' (L) are used to identify individual statements and associate them to the corresponding concept.

Analysing the phenomenon of range anxiety

From the analysis (open coding), two core concepts emerged, namely, the experience of a *limited range incident* and the psychological manifestation of *range*. These concepts consist of a set of descriptors and attributes explained in the following.

Characterising a limited range incident

Two respondents [R1, R7] experienced an limited range incident. One of the EV drivers got stranded 5 km from home [R1]while the other EV driver aborted the journey and stopped 5km from the final destination to find a power outlet [R7].

Both drivers judged, at the start of the trip, that they would have enough energy to be able to get to the destination [R1-L31/R7-L308-L408]. The turning point, in which the participants realised that they would not be able to reach their destination, occurred along the journey, as the state-of-charge was at the end, and dropping more rapidly than expected (i.e., it was experienced that the charge changed faster at the end of the scale compared to when the EV was almost fully charged) [R1-L39/R7-L252]. That is, the incident was a *surprise* to the respondents.

One respondent chose to drive the EV as close to home as possible, to be able to tow the EV the last bit [R1-L42]. The other driver drove the EV off the motorway, to be in a less inconvenient place to run out of power and also to have the opportunity to find a power outlet [R7-L261]. In other words, when faced with the prospect of running out of charge, both drivers identified a *strategy* that gave them enough confidence to let the incident to evolve.

In general, a set of intertwined factors (causes) made the incident (limited range) occur for both EV drivers [R1, R7].

First of all, the limited range incident happened in the first week for both drivers [R1-L10-L54/R7-L259]. Both refer to the fact that they had *not yet learned the behaviour of the EV* [R1-L390/R7-L310-L259]. That is, the answers provided indicate that they blame themselves for ending up in the incident; the situation is not blamed on the limitations of the EV. In addition, *unforeseen* incidents during the day contributed. For instance, R1 performed a longer trip than usual that day [R1-L19], combined with the fact that he then had not enough time to charge it during the day [R1-L29], and a stop at the food store on the way home [R1-L36]. In addition, they did not foresee that the battery level would disappeared faster at the bottom half of the state-of-charge scale compared to when the battery level was at the top [R1-L39/R7-L252].

Third, a contributing factor was the difficulty to *understand the information provided* regarding the state of the EV and the identification of a correct action. R1 reported that he did not know the meaning of the message: "warning low battery" and "very low battery" [R1-L7]. Further, R1 did not have an range estimation that reflected long he could go on one charge (R1-L71]. He could therefore not take the correct action. R7, on the other hand, reported that he saw that the last bit on the state-of-charge indication was lit. However, he could not judge how long he could actually drive with the EV [R7-L278-L304]. This, in combination with an uncertainty regarding the meaning of the range estimation (In the words of R7: "How long is 10 kilometre in the world of electrical vehicles" [R7-L497]), made R7 uncertain of the status of the EV and the *available resources*. The main problem was that the range estimation was not estimated on the current driving behaviour. Indeed, R7 had previously driven in city traffic and was at this occasion on a highway for the first time [R7-L308-L309-L316-L408].

During the incident, both drivers took actions to extend the range of the EV. R1, for instance, drove more calmly at the end to be able come as close as possible to home [R1-L79]. R7 drove off the motorway, which would implicitly allow a lower speed [R7-L307].

The effect of a limited charge situation

Both of the respondents [R1, R7] who experienced a limited range situation expressed a strong desire to not end up in the same situation again [R7-L268/R1-L11]. That is, there was strong psychological effect of the situation.

The intensity of the experience could be connected to the problems in solving the situation. R1 had identified a solution which involved towing the EV back home, however, it was found out that the car did not have the right equipment to be towed [R1-L43]. R1 had to spend a lot of time trying to find and order the equipment to be able to tow it [R1-L46]. For R7 the solution was to drive off the motorway to find a charging spot, however, the gasoline station refused to help him charge the EV [R7-L261], luckily, the driver saw a garage which could let him charge the EV for 1,5 hours, enough time to allow him to continue. That is, the "worry" was the inability to solve the situation, and the possibility to, again, end up in a situation in which could not be solved. Hence, any previous "worry" was confirmed.

The critical incident made R1 notify others, who could be using the EV of the criticality of the range [R1-L59]. He recommended at a minimum of a quarter of charge [R1-L60] before taking the EV and that the EV should always be connected and charging while on its parking spot [R1-L62]. The underlying strategy was to have a buffer in case of unforeseen incidents [R1-L135]. R7 always kept the EV fully charged [R7-L274]. In addition, R1 used the EV less often after the incident [R1-L11]. For R1, the range became the major concern after the incident [R1-L207]. The change in behaviour indicates a behavioural effect of the incident.

Further, both R1 and R7 expressed a strong request for a back up solution (in addition to their own strategies identified above), which would limit the chance of experiencing the situation again. R1 suggested a back up solution of a second engine [R1-L196] while R7 suggested publicly available charging points [R7-L350]. Interestingly, the intensity of the request was stronger compared to those respondents not ending up in a limited range situation.

Reacting to a limited range incident

While R1 reported a feeling of frustration [R1-L107], R7 reported a negative feeling of being 'left out' [R7-L324] when experiencing the limited range incident.

Interestingly, R1 got angry/frustrated with himself for ending up in the situation in which he got stranded [R1-L107], arguing that in hindsight he should not have taken the chance [R1-L108]. Similarly, R7 reflected upon the fact that apparently he had not learned the behaviour of the EV yet, indicating that this was the reason for him ending up in the limited range situation [R7-L305-L310]. That is, both respondents did not become frustrated of the abilities of the EV as such; rather the frustration was directed at their own abilities of managing and understanding the limitations of the EV.

To continue, when R1 realised that he would not be able to reach home, he got into a state of acceptance [R1-L116-L41]. This state probably emerged because he had identified a solution to the problem (get someone to tow him the last bit) [R1-L267] and the fact that he could not do anything else to affect the situation [R1-L41]. Similarly, R7 reacted by accepting the situation and tried to find a solution by driving of the motorway [R7-L261].

Interestingly, both respondents received similar information to react upon. R7 reacted to the warnings provided (the sound and the blinking) and immediately tried to find a power outlet [R7-L260], while R1 reported that he received text warnings "low/very low battery", however, he did not react in the same way as R1, instead choosing to continue his journey [R1-L41]. The difference in information between R1 and R7 was that R7 had access to range estimation.

For R1, the situation as such caused a type of stress (as opposed to a anxiety) that could be connected to the situation one might end up in. R1 expressed that the experienced stress is enhanced if one 1) has an appointment that one cannot be late to, 2) is carrying other people in the EV, or 3) just has the car full of food, all of which would make the situation 'a stranded EV by the road without energy' more severe and complicated [R1-L159].

Interestingly, R1 and R7 both took the incident as a 'confirmation'. For R7 it was a confirmation that it is not that easy to get access to a power outlet while in need (he got turned down at the first try [R7-L268]. For R1 it was a confirmation that the limited range may be a concern [R1-L215].

Driving with limited range

All respondents were aware of the range and thus, adapted their behaviour accordingly, and thereby avoided a situation in which they would be affected by limited range or experience range anxiety [R1-R8]. To avoid these situations, several *coping strategies* were identified (cf. Table 2). The most prominent coping strategies were the following:

- Drive calmly, in an energy efficient way using the "eco drive mode".
- Use a safety buffer to have the possibility to make unplanned trips along the way/drive in an less energy efficient manner
- Get to know your EV (i.e., learn its limitations and learn to react correctly to the information provided)
- Use the indicators provided in the EV to judge the state of the EV, to make sure you do not end up with limited energy.

One respondent [R8] reflected upon the fact that he did not experience range anxiety because he always felt in control; he always knew the where he was going (pre-defined destination) and the current range [R8-L167]. The above statement is implicitly reflected upon in the respondents driving patterns. Usually, a reoccurring pattern given by normal routine (e.g., home-work) was utilised [R1-L20/R2-L14-L55]. Interestingly, many trips were to single location (i.e., back-and-forth to one destination, as opposed to multi-location on the same trips) [R1-L15/R4-L41/R5-L61/R6-L20/R8-L21]. In addition, the EV were driven to known locations [R3-L29/R4-L37], and used in short trips [R6-L25/R8-L16]. Furthermore, it was stated that the EV was used for weekday activities [R7-L29]. It should be noted that the driving pattern could reflect the context of use/EV loan schema as well as whether or not the driver used the EV for commuting (cf. Table 1).

Several of the respondents had occasions in which they chose to not take the EV due to range [R1/R8-L36] or convenience. In such situations another form of vehicle, e.g., public transport, gasoline car[R8-L36] or a bike [R6-L51] were chosen.

In addition, the EV was chosen in situations in which there was an added value to taking the EV. Examples of value concepts are: *environmental friendly:* you feel good when driving [R1-L208/R2-L336/R3-L104/R4-L10/R6-L42/R8-L28/R7-L7], *comfort*: better to use in bad weather, etc. [R8-L17/R6-L54]), *convenience*: it is always charged in the morning, it is easy to park, easy to turn, i.e., it is a small vehicle [R4-L74/R6-L57-L58/R8-L20]), *branding:* nice to be seen in an EV [R8-L32/R5-L27/R8-L31], and not to forget, *fun:* it is quick to accelerate at the start and therefore fun to drive [R7R8-L32-L30], it is a *quiet* vehicle [R1-L202/R2-L325/R3-L104], and it is *automatic* [R2-L315].

Table 2. Coping strategies utilised to limit the possibility for limited range incidents to occur

Coping strategy	Description	Placeholder (Respondent, Line)
Planning	A conscious decision to organised the EV trip before it starts	[R8-L72-L75/R7-L155-L160/R6-L226 /R5-L148-428/R4-L328]
Control	Check/control the exact distance to the destination online, making sure that it can be reached	[R8-L79/R5-L462-L476-L493]
Shortest way	Take the shortest; not the fastest way	[R5-L160-L497]
Avoidance	Do not use the EV when you are unsure that you can reach your destination	[R8-L121-L36-L181/R7-62-L159-L64-L510/R6-L156/R5-L88-L153-L303-L310/R4-L45-L83/]
Energy outlet	Drive energy efficient, turn of equipment which is not necessary, e.g., AC	[R8-L209-L59-L62/R7-L997-L283-L293/R6-L72-L223L74-L174/R5-L360-L373L163-L163-L171-L182/R4-L168-L163/R3-L179-L212/R2-L97-L105/R1-L80]
Budget management	Adopt a driving behaviour which corresponds to the driving distance (aggressive/non aggressive driving]	[R6-L72-L176-L199/R5-L93-L351]
Awareness	The mental awareness of driving in a limited range vehicle	[R7-L523/R6-L176/R5-L148-L208-L438/R4-L41/R6-L79-L160]
Safety buffer	The minimal remaining range the drivers wanted to use (which could be used to make unplanned trips)	[R8-L131/R7-L239-L278/R6-L162-L105/R1-L142/R4-L52/R3-L116]
Guided driving	Never drive to unknown places without support (GPS)	[R5-L155/R4-L297]
Resources	Check beforehand that there is a charging spot at the destination (call, online, etc.)	[R8-L43-L417/R7-L259/R5-206/R4-L326]
Know your EV	Learn the range of the car based on own experience	[R8-L280-L332/R7-L58-L305-L600-L446-L445/ R6- L77-L168/R4-L134/R5-L474/R2-L123-L123-L54/R1- L31-L175]
Backup	Identify solutions to running out of energy	[R8-L238-L255]
Car status awareness	Use the information provided by the car, e.g., range estimation, power meter, state of charge to know the state of the EV	[R7-L608/ R6-L186-L237/R5-L230-L374-L599-L168-379R5-L599/R3-161/R4-L148]/R1-L171]
Comfortable zone	The distance the drivers drive every day, in which one only drive to know places	[R7-L441/R2-L14/R5-L463]
Limit of charge	Have a limit/ fixed limited of charge below which the EV is not taken; always have the car fully charged	[R6-L162/ R5-L203/R4-L41/R3-L63-L66-L112-L253/R1-L61-L237]
Goal driven driving	Always have a pre-determined destination before you start your trip	[R5-L447]
Adjustability	Allow yourself the time frame needed to drive according to your battery level	[R5-L449]
Limit of distance	Have a distance limit that determines whether or not the EV should be taken	[R4-L120/R2-L307]
Context	A pre-defined context of use (e.g., city drive, excluding specific roads such as motorways)	[R3-L86/R1-L152-L250]

In addition, it is *exciting* [R6-L66], and *timesaving*: you do not need to spend time going to the gasoline station to charge it, you do it at home while sleeping [R6-L75]. Actually, it was argued that the added values balance the negativisms of range [R1-L125/R3-L103].

While driving in the EV, the drivers used *estimated range*, *state-of-charge* and the *power meter* (eco driving) as information sources. From these, estimated range were judged as most important [R1-R8]. In the analysis, it could be seen that the information was utilised to increase the awareness of the current situation and position oneself and ones own actions in in relation to the range.

The manifestation of range anxiety

When the respondents are asked about what they are concerned about while driving an EV, four of the respondents mentioned range [R1-L207/R2-

L64/R3-L102/R7-L456] while three mentioned that they were not worried about anything particular while driving an EV and two mentioned safety [R6-L109/R8-L141].

When analysing the data, the phenomenon of range anxiety, cannot be described as an anxiety as such. Rather it manifests, as an awareness of the current range, to which the driver adapts via coping strategies [R1-R8]. More specifically, a set of concepts emerged from the analysis, which indicates how range anxiety manifest (cf. Table 3).

Table 3. Range anxiety descriptors

Descriptor	Placeholder (Respondent, Line)
Awareness of current resources	[R1-L119-L208/R2-L65-L83/R3-116/R5-L438/R6-L190/R7-L113-L99-L493].
Uncertainty regarding technology/information provided	[R7-L58-L72-458/R1-120-L255/R2-L192/R5-L337/R6-L142]
Stress of a future situation	[R1-L159]
Worry of the unknown	[R4-L207/R4-L399]
Thoughts of the limitations	[R1-234/R2-L83/R5-L441]
Superstition that it will be a potential problem	[R1-L128]
Concern of a potential problem	[R4-L326]
Lack of trust in the information provided	[R3-L54/R3-L53]
Expectation that incidents will emerge	[R1-L218]
Reluctance to use the EV for long distances	[R6-L135]
Guts to challenge the range	[R3-L49]
Pro-activeness	[R7-L162-L239]

Range anxiety (cf. table 3) can be further described as something being *constant*; it is always present [R1-234/R2-L83/R5-L441] although it can vary in *intensity* [R1-L234/R2-L161], and it becomes a *habit* [R2-L161].

Furthermore, the analysis indicates that the anxiety is connected to the problems of charging of the EV (i.e., placement and the number of charging spots and the time it takes to charge). R3 refers to the long time it takes to re-charge the EV [R3-L135/R7-L341], with the effect that it takes a long time until it can be used again [R2-L84]. R7 refers to the problem of finding a power outlet when in need [R7-L73/R4-219/R5-L252]. That is, the worry was directed towards the situation one might end up in, specifically towards the potential inability to solve the situation. Indeed, R3 reflects upon the fact that there is no "reserve" [R3-L120].

Some respondents refer to possible consequences. For instance, one may be late to appointments [R7-L339/R1-161]. If one has been shopping for food, there may be issues in storing the food in case of a break down [R1-L160]. It is argued that these factors contribute to the experienced stress.

Furthermore, the EV represents a new technology of which the drivers have not had that much experience. Indeed, range anxiety can be associated to an uncertainty of EV technology. For instance, it may not be clear what "driving on the reserve" in an electrical car involves [R2-192/R7-L498]. Also, it may not be clear how the battery will be affected over the long run [R2-L216/R6-L140].

Similarly, range anxiety can also be connected to the trust in the system; if the driver had calculated that the battery would be enough but that turned out to be incorrect (cf. critical incident of [R1, R7]), this driver may lose some trust in the system [R1-L255].

Affecting range anxiety

The respondents were specifically asked about what aspects they thought would affect range anxiety, based on their own experience of driving an EV. The analysis provided the following concepts (single or in combination):

- Estimated range indication [R1-L171/R2-L187/R4-L462/R5-L377/R6-L209]
- State-of-charge indication [R1-L190/R2-L199]
- Power meter indications [R5-L379]
- (Fast) charging stations [R3-L140/R4-L401/R6-L532]
- Knowledge/experience [R1-L175/R2-L193/R4-L465]
- Smart Navigation [R5-L388]
- Energy use of other equipment [R2-254]
- Your own back up system [R3-L145/R4-L404]
- Battery quality [R6-L209]
- Knowledge of under what circumstances estimation of range is accurate [R6-L497].

What is notable in the above list is that most respondents want more accurate details regarding the current state of the EV itself and the environment outside the EV. This is expressed as a difficulty to understand the current status of the EV and what effect it had on the range, and might be connected to the fact that it is difficult to judge the energy/km relationship [R2-L196/R6-L213].

Charging your EV

Most respondents charged the EV over night at its home destination [R1-L236/R2-L28/R3-L46/R4-L52/R8-L90]. Some of the respondents charged the vehicle at work [R1-L29/R2-L27]. Only one [R7] charged it along a pre-defined journey. One respondent also charged at the end destination [R8-L85]. R6 reflected upon the positive effect of charging the EV during night: there is no need to set aside specific time to go to a gasoline station to "fill up on petrol" [R6-L75].

Most of the respondents fully charge the EV, and always charge the vehicle at its parking spot that has access to charging [R1-L63-L237/ R2-L28/ R3-L60]. At rare occasions, the vehicle was charged during daytime. The aim would be to refill the EV as much as possible before the next use [R1-L29/R4-L58] and this charging behaviour might be reflected on the fact that it was company pool EV. Further, some respondents only charged it when they were aware of an upcoming need to have it fully charged [R4-L53], or when they wanted to enable flexibility in their planning [R6-L99].

The charging behaviour could be connected to range anxiety. Respondents argued that they wanted to have the EV fully charged as a safety precaution [R1-R8].

The use of public available charging spots was considered as positive [R4-R7]. How such publicly available charging points should be organised differed among the respondents.

Some respondents argued that it could be problematic to book a charging spot [R7-L213], as it might limit the flexibility [R7-L215/R8-L99]. Specifically, while it might be ok to have to book a slot during night-time [R6-L93], booking one during the day may be too restrictive [R6-L95]. Further, having to book might be acceptable if it was integrated with a pre-existing task such as planning a trip (i.e., you book when you check the distance to your destination) [R8-L96]. One respondent saw it being natural to book a charging spot as we need to book everything anyway today in society [R5-131]. Booking may provide the security of knowing that there will be a spot available for you [R5-L135].

In addition, it was argued the charging should be at a convenient location, such as a dinner place, where it is natural to stop for a longer time [R4-L233]. This argument is similar to the argument to charge the EV during night, while sleeping. That is, having to explicitly wait for the EV to charge is undesirable. This is similar to the argument of R4: If you need to book a charging spot, then that is a sign that there are not enough charging spots [R4-L227].

4. Conclusion

Issues to be investigated in questionnaire study

In this study it has been shown that driver adapt to the limitations of the EV to the extent that they do not consider range anxiety a major concern while driving the EV. Interestingly, it is also shown that range anxiety is beyond being triggered by a critical incident such as becoming stranded along the way. Rather, it is a constant mental awareness of available resources, used as a decision benchmark determining the use of the EV.

Main findings and initial recommendations

Base on what has been identified in this report regarding range anxiety the following initial recommendations can be made. Each finding (F) is summarised along with its corresponding *initial* recommendation (R).

- F1. Range anxiety is manifested as an constant awareness of current available resources
  - *R1. The driver should be able to understand the current state of the vehicle*
  - *R2. The driver should be able to understand the future state of the vehicle*
  - R3. *The driver should be able understand the effect of their own actions*
- F2. Coping strategies are used to exclude the experience of a limited range incident
  - *R4. The driver should be able to judge whether or not the final destination can be reached*
- F3. The occurring of limed range incidents were associated to the abilities of the driver to manage the EV
  - *R5. The driver should be provided with the necessary information to be able to learn how to correctly interpret the behaviour of the EV*
  - *R6. The information provided to the driver should be understandable, correct, constant, and transparent.*
- F4. Range anxiety exist due to the uncertainty in the EV technology
  - *R7. See above recommendations*
- F5. Range anxiety exist due to the uncertainty in the existing solutions to limited range incidents
  - *R8. The driver should be able to judge where the possible charging stations are located*
- F6. The decision, weather or not the final destination can be reached, is done previous to sitting down in the EV

It should be noted that the above recommendations should be viewed in the context of the findings of the study. That is, its generalizability has not been evaluated.

Future work

Future work includes a questionnaire study involving about 40 participants from several different studies in Sweden, having experience of different types of EV brands. Due to the results of this study, the future questionnaire study will focus on the notion of control, trust and awareness with the purpose to create a range anxiety model and a range anxiety sensitivity scale.

Bibliography

Scientifically published material

Agassi, S (2009) World Without Oil Better Place Builds a Future for Electric Vehicles. *Innovations: Technology, Governance, Globalization*, 4

Beckers, J. J., Wicherts, J. M., Schmidt, H. G. (2007) Computer Anxiety: "Trait" or "State"? *Computers in Human Behaviour,* 23, 2851–2862

Botsford, C. & Szczepanek, A. (2009) Fast Charging vs. Slow Charging: Pros and cons for the New Age of Electric Vehicles. *EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium*. Stavanger, Norway, May 13-16, 2009

Brady, J (2010) Electric Car Cultures: An ethnography of the everyday use of electric vehicles in the UK. *Masters thesis, Durham University*. Available at Durham E-Theses Online: http://etheses.dur.ac.uk/690/

CABLED (2010), UK's Largest Electric Vehicles Trial – First Findings, [online] Available at: http://cabled.org.uk/press-download/uk-s-largest-electric-vehicle-trial-first-findings, [2011-04-01]

Caroll, S. (2010) The smart move trail: description and initial results. *Technical report: Cenex*. Available at: http://www.cenex.co.uk/LinkClick.aspx?fileticket=yUKAcRDJtWg%3D&tabid=60

Cocron, P., Buhler, F., Neumann, I., Franke, T., Krems, J. F., Schwalm, M., Keinath, A., (2011) Methods of evaluating electric vehicles from a user's perspective – the MINI E field trial in Berlin. *Intelligent Transport Systems IET*, 5 (2), 127-133

Franke, T., Buhler, F., Cocron, P., Neumann, I., Krems, J. F., (2011). Enhancing sustainability of electric vehicles: A field study approach to understanding user acceptance and behavior. *Manuscript submitted for publication*, February 3, 2011

Hamilton, B., & Summy, M. (2011) Benefits of the smart grid: part of a long term economic strategy. *IEEE Power Magazine.* In my view, January/February, 101-102; 104.

Lane, B. & Potter, S (2007) The adoption of cleaner vehicles in the UK: exploring the consumer attitude- action gap. *Journal of cleaner production,* 15, 1085-1092

Mesken, J., Hagenzieker; M., Rotthengatter, T. (2008) A review of studies of emotion and road user behaviour. IN: Down, L., (ed) *Driver behaviour and training vol* 3. Achgate Publishing

Morton, Schuitema and Anable: EVs: Will Consumers get Charged Up? Technical document, Open University, Milton Keynes. Available at: http://design.open.ac.uk/documents/Morton2011.pdf

Pearre, N., Kempton, W., Guensler, R. L., Elango, V. V. (2011) Electric vehicles: How much range is required for a day's driving? Transportation Research Part C: Emerging Technologies, Article in Press, Corrected Proof

Philip, A. & Wiederer, R (2010) Policy opinions for electric vehicle charging infrastructurein C40cities. *Technical report*, Harvard Kennedy School. Available at: http://www.innovations.harvard.edu/cache/documents/11089/1108934.pdf [2011-05-20]

Sonnenschein, J. (2010) Preparing for the Roll-Out of Electric Vehicles: Exploring how cities can become plug-in ready. IIIEE Theses 2010:XX. Lund University, Sweden.

Taylor, D. (2009). The Differences and Similaritities between Plug-in Hybrid EVs and Battery EVs. 24th International Batteries, Hybrid and Fuel Cell Electric Vehicle Symposium (EVS24), Stavanger.

Tate, E. D., Harpster, M. O., & Savagian, P. J. (2008) The Electrification of the Automobile: From

Conventional Hybrid, to Plug-in Hybrids, to Extended-Range Electric Vehicles. SAE technical paper series 2008 World Congress. Reprinted From: Advanced Hybrid Vehicle Powertrain, 2008. Detroit, Michigan, April 14-17, 2008, (SP-2153)

Valentine-Urbschat, M., & Bernhart, W. (2009) Powertrain 2020- The future drives electric. Technical report. The RolandBerger strategy consultants. Available at: http://www.rolandberger.com/media/pdf/Roland_Berger_Powertrain_2020_20110215.pdf [2011-06-01]

Wellings, T., Binnersley, J., Robertson, D., Khan, T (2011) Human machine interfaces in low carbon vehicles: Market trends and user issues. Dokument No. HMI 2.1. Low carbon vehicle technology project: workstream 13. Available at: http://www2.warwick.ac.uk/fac/sci/wmg/research/low_carbon/automotive/lcvtpevents/ws13_hmi_in_lcvs_market_analysis_and_user_issues_v2_1.pdf [2011-05-25]

Weiller, C., (2011) Plug-in hybrid electric vehicle impacts on hourly electricity demand in the United States. Energy Policy, Vol 39, Issue 6, June 2011, Pages 3766-3778

Wynn, T & Leafeur, S. (2009) A free market perspektive on electrical vehicles. Technical Report, CascadePolicy Institute. Available at:

Zeidner, M., Matthews, G. (2005) Evaluation anxiety: current theory and research. In Handbook of competence and motivation A. J Elliot, (ed)

Zeidner, M., Matthews, G. (2011) Anxiety 101. The Phych 101 series. Springer Publishing Company, LLC.

Appendix 1- Range anxiety definitions

Range anxiety as it is portrayed in literature (cf. External report, "the phenomenon of range anxiety".

Reference	Definition
Taylor (2009)	"range anxiety is a psychological construct"
Tate, Harpster, & Savagian (2008)	"their [road users] continual concern and fear of becoming stranded with a discharged battery in a limited range vehicle"
Agassi (2009)	"range anxiety," the driver's fear of reaching the end of the charge and not being able to go anywhere for hours"
Brady (2010)	"range anxiety, which describes the apprehension arising from the relatively high likelihood that the vehicle will run out of power before reaching a destination, and is described as being similar to the anxiety experienced when driving a combustion engine vehicle which is low on fuel with the nearest fuel station a significant or unknown distance away.
Pearre et al., (2011)	"… driving with little energy remaining in the battery, sometimes dubbed ''Range Anxiety''
Sonnenschein (2010)	"Overall there is strong empirical evidence that the current range of BEVs matches the usage patterns of most drivers but does not match their expressed demand. The problem is not range but range anxiety".
Weiller (2011)	''Range anxiety'' is a term that comes up frequently in public concerns about PHEVs and placing public charging stations in as many places as possible will help to reduce the fear of ''running out'', especially in the case of EVs (PHEVs can continue driving in gasoline mode)."
Wynn & Laefeur, (2009)	"People are concerned that electric vehicles cannot travel far enough on a single charge, and they may have difficulties recharging. Additionally, they are concerned about the time required for a charge, and the potential inaccessibility of charge stations"
Botsford & Szczepanek (2009)	"interestingly, TEPCO reports that the second charger was used only sparingly. This illustrates a phenomenon describes as "range anxiety". In this case, just knowing that the EV service vehicle could be recharged during the day reassured EV drivers that they would not be stranded"
	"Due to the long charging time required for advanced automotive batteries, there are concerns that the millege of electric vehicles will not be great enough to cover an entire trip without charging "
Hamilton & Summy 2011	A major concern of potential electric vehicle users is "range anxiety"
Philip & Wiederer 2010	"Range anxiety is the fear of being stranded in an EV due to inadequate battery capacity / performance … As explained previously, range anxiety is the psychological phenomenon where people are afraid of running out of charge on a highway and want the assurance that in this case a charging station is close by. It is important to note that range anxiety is not describing the actual charging process for such a case – but people being afraid from such a hypothetical case and therefore demanding a certain kind of charging infrastructure, even though they might not actually use it."
Valentine-Urbschat & Bernhart, 2009	"The limited driving range of pure EVs creates what is known as "range anxiety." This affects drivers as soon as the battery charge falls below 50%."
Wellings et al., (2011)	"fear of running out of charge"

Appendix 2- Interview Template[3]

The list of question to be used as a guide when performing semi-structured interviews

I would like to talk to you about your experiences of EVs. Your answers will be a part of a EU project, which purpose is to design new services for EVs.

I would like to inform you about some aspects before we start the interview. Your responses will be treated anonymously. You can choose to end the interview if you want. You can choose to not answer a particular question. This session will be recorded for documentation purposes. The interview will take about 45 (-60) minutes.

START - BACKGROUND

1. What is the brand of the EV that you have been driving?
2. How long have you had access to your EV?
    a. How often have you used your EV in your daily life?
3. How long distances did you typically drive in your EV?
    a. Is this different to your driving in your "regular gasoline car"?
4. For what purposes have you used your EV?
    a. Is this different compared to your "regular gasoline car"?
5. Do you plan in any particular way when you drove your EV?
6. Where did you typically charge your EV?
7. What made you decide that it is time to charge your EV?
8. How "fully charged" did you usually let your EV be?

GENERAL CONCERN

9. What were you most concern of while driving your EV?
10. Did this change during the time you tried the EV?

RANGE ANXIETY- CONCEPT (come back to the questions at the end of the interview if necessary)

11. Have you heard about range anxiety?
    a. What do you think of when you hear that word?
12. How would you explain range anxiety to people you meet?
13. What do you think is the reasons behind range anxiety?
14. What aspects do you associate to range anxiety?
15. Do you think range anxiety is a problem?

RANGE ANXIETY- EXPERIENCE

16. Could you describe an event (situation) in which you experienced that you were about to run out of charge?
    a. Can you describe how you reacted in this situation?
    b. What made you react this way?
    c. At what moment did you start to think that you may have problem with range?
    d. Was it a surprise or did you expect this situation to happen?
    e. Have you experienced this often?
    f. Is this experience similar to any other experience you previously have had ?
    g. In this situation, what made you uncertain that you may reach your destination?

[3] NOTE: Translation from Swedish to English

h. What would make you feel more certain that you could make it to your destination in that situation?

RANGE ANXIETY- BEHAVIOUR

17. When you are in such as situation when you feel unsure that you will reach you destination, what type of information do you use in you EV? Do you look for anything particular?
18. What do you do to be sure that you will be able to reach your destination? (Do you have any strategies)
19. What do you do to avoid such a situation in which you may have problem with range?
20. Have you ever done/would do anything special, to extend you range?
21. If/when you end up in a situation in which you are out of battery/range, what would you do?
22. Do you trust the information provided to you via the EV?
23. Does the information change during the journey?

IMPROVEMENTS

24. How did the information services in the car help you during your journey? How did you use the information provided to you?
25. What information service would make you more certain that you would reach your destination?
26. What information service are you missing today?
27. What information service did you appreciate the most in your EV?

END

28. Is there anything you would like to add (which we have not talked about yet)?