ELECTRIC VEHICLES

THE PHENOMENON OF RANGE ANXIETY

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Executive Summary

Current issues and market trends in range anxiety

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

This report details research activities carried out by Lindholmen Science Park as part of the work package 1300 within the ELVIRE project. This report describes the phenomenon of range anxiety.

The overall objective of the report is to:

- Identify the key elements of range anxiety
- Identify current approaches to limit range anxiety
- Identify current approaches for measuring range anxiety

To address these objectives, this report details the current issues and market trends associated with range anxiety. The goal of the report is to provide the necessary means for further empirical studies of range anxiety.

The scope of the work is restricted to what has been publicly published online.

Main findings

Range anxiety emerged as a concept in the late 1990s and captures a drivers' concern of not reaching their destination while travelling in an EV. Range anxiety relates to the technical limitations of the batteries in EVs.

Range anxiety is a complex phenomenon and the findings are somewhat contradicting.

Field trials have established that range anxiety can be dynamic, it can increase as well as decrease with experience, and it can depend on personal traits, as well as be affected by the situation in- and outside the EV.

Range anxiety is typically portrayed from a market perspective while identifying current market barriers for full-scale adaption of EVs.

The insights regarding range anxiety have typically emerged in pre/post trials, grounded in interviews and questionnaires.

At present, there are a number of different market trends to solve the *situation* in which the driver experience range anxiety, these approaches include, but are not limited to:

- Provide information about the current situation inside-and outside the EV
- Provide strategies to prevent the situation
- Limit the risk of the situation occurring
- Eliminate the consequences of the situation
- Provide a solution to the situation while occurring

It should be noted that it is not typically elaborated upon *how* the listed approaches actually reduce range anxiety, and to *what effect* or *why* it actually reduces it. To this end, more research is needed to fully understand the range anxiety phenomenon.

Content

1. Introduction

Introducing the terminology, aim and objectives of the report.

Range anxiety in EVs[1] refers to "[road users] continual concern and fear of becoming stranded with a discharged battery in a limited range vehicle" (Tate, Harpster, & Savagian, 2008). The existence of range anxiety is related to the technical limitations of the batteries of EVs (Botsford & Szczepanek, 2009). The range of a battery charge not only depends on the driving style (the range, for instance, decreases with aggressive or high speed driving) but also on factors like terrain and road condition, outside temperature or air conditioning usage, further, the age of the battery can be a factor. The range can thus vary along the journey as well as across time, which may cause concern for the driver.

Range anxiety is typically mentioned as the main factor affecting the penetration of EVs on to the global market together with long charging times and a high purchase price (Parsons, 2011). It is repeatedly maintained that range anxiety is the one reason that may hinder the success of EVs (Parsons, 2011; Wynn & Lafleaur, 2009; Wellings et al. 2011; Botsford & Szczepanek, 2009;).

It is argued that this will be especially true for the European market because we are more likely to be in the possession of just one single car, as compared to the US market, where people typically own more than one car. However, others (Assassin, 2009) argue that the effect will be greater in markets such as the US as they are custom to a greater mobility and longer routes. He continues to claim that it will be easier to penetrate markets such as China and India as "people will be more than satisfied to have any range at all".

The concept of range anxiety is, thus, typically approached as an initial perception (concern) of prospective consumers from a market perspective. What is notably lacking is a deep understanding of range anxiety from a cognitive perspective.

In 1998, authors acknowledged "there has been little published research about electrical vehicle trials, in part because they are infrequent, and in part because the results are usually proprietary" (Golob & Gould, 1998).

12 years later, Sonnenschein (2010) claims: "Another fruitful research area is the somewhat mysterious occurrence of range anxiety. A deeper understanding of the discrepancy between consumer needs and consumer wishes can help to develop strategies to reconcile the one with the other, even if large improvements of EV range are not to be expected very soon".

The high level objective of this report is thus to conceptualise the phenomenon of "range anxiety" from a cognitive perspective and thereby provide the necessary means for further empirical studies. The objectives are as follows:

- Provide an overview of what is currently known about the phenomenon of "range anxiety".
- Present current market trends to limit range anxiety.

The goal of the report is thus to provide insights and identify enablers that could affect range anxiety, and thereby, identify strategies that have potential to limit range anxiety.

[1] Electrical Vehicles (EVs) refer to both Plug-in Hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicle (BEVs).

2. The Concept of Range Anxiety

The phenomenon as portrayed in scientific publications; its nature and cause

2.1 Anxiety

"In every day life, anxiety functions as a warning signal for often unspecified pending danger and serves as a prime for developing an adequate coping response" (Beckers et al., 2007). "Anxiety is considered to be a basic negative emotion, along with anger, sadness, disgust, and perhaps others… [a]nxiety is not the same as the emotion of fear which is associated to an immediate danger, rather, anxiety corresponds to a state of uncertainty " (Zeidner & Matthews, 2011, p. 1).

Mesken et al. (2008) refer to the following definition of anxiety "subjective feelings of tension, apprehension, nervousness and worry, as well as activation or arousal of the autonomic system" (Speilberger, 1970). Thus, anxiety can be experienced through both mental and physical symptoms. More specifically, "the state of anxiety is accompanied with by feelings of nervousness and tension, as well as worries and intrusive thoughts. It is also typical to experience signs of bodily activation, sometimes described as the "fight-of-flights" response, such as pounding heart, perspiration, and gastric disturbance" (Zeidner & Matthews, 2011, p. 2).

Anxiety is often future oriented and directed towards external threats (Zeidner & Matthews, 2011). In addition, the level of anxiety is personal, and can change between different persons and situations from little, moderate, to excessive.

Anxiety can be beneficial, e.g., by motivating the person to deal with the threat (e.g., via coping strategies), as well as detrimental, e.g., by being a source of distraction that interferes with a successful goal-directed action (Zeidner & Matthews, 2011).

In general, there are two categories of anxiety: *trait* anxiety and *state* anxiety. The enduring personality distortion (*trait*) and the immediate experience of anxiety (*state*). For instance, a temporary state anxiety will pass away, usually when the source to the anxiety has been taken away. Indeed, "[b]y definition, a temporary anxiety will subside, and special training or mere exposure [to the cause]… may reduce this type of anxiety. A trait-like anxiety will be more difficult to treat as the source of the anxiety is more deep-seated" (Beckers et al., 2007).

Anxiety can come in a variety of forms and, similarly, its behavioural consequences can vary along with contextual and personal factors. In general, anxiety is related to three subsystems (Zeidner & Matthews, 2011; Zeidner, Matthews, 2005):

- Subjective subsystem (cognitive: worry, irrelevant thinking);
- Physiological sub-system (affective, bodily reaction)
- Behavioural sub systems (coping strategies).

Anxiety can be related to not only higher emotional focus (e.g., trying to control anxiety symptoms) and avoidance (e.g., trying to not think of the situation) but also to lower task focus (e.g., focusing on the effort of task performance). It has actually been argued that emotion-focused coping and avoidance both appear to predict state anxiety (Zeidner & Matthews, 2005).

Anxiety can be a general personal trait, or specific such as computer anxiety, test anxiety, etc.

2.2 Range Anxiety

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

In general terms, range anxiety can be explained as the fear of a possible negative future event and/or

consequence. This may be evoked by the thought of the event/consequence or a physical experience.

Range anxiety can be classified in a similar manner as computer anxiety (cf. Becker et al., 2007); it is an anxiety towards a specialised situation, and it can be temporal as well as dynamic (change with exposure). It could therefore be argued that range anxiety can be classified as a *context-linked* and *situation-specific* form of anxiety (cf. Zeidner & Matthews, 2011).

It is believed that range anxiety was first reported in the press in 1997. In 2010 General Motors filed to trademark the term for the purpose of "promoting public awareness of electric vehicle capabilities"(Link 20). Indeed, in early studies such as Kurani, Turrentine, Sperling, (1996) and Golob & Gould, (1998), the phenomenon of "range anxiety" is phrased in terms of "limited range".

Range anxiety is, in many ways, an intuitive term which are most often defined as *perceptions* or the *experience* of drivers regarding the *fear of not reaching your destination* when you are in an EV (cf. Table 1).

Some definitions refer to the problem of recharging the EVs, that is, the phenomenon may not only relate to the occurrence of the particular situation but also to the available actions needing to be performed when in a situation in which the destination can no longer be reached (cf. table 1).

TABLE 1. Definitions 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 millage 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"

Re-viewing the definitions/descriptions of range anxiety (cf. Table 1), the following can be concluded: Range anxiety can be, (a) the worry of experiencing such a situation in the future or present (b) the worry of what will happen if such a situation emerges (c) the worry of not being able to find a solution to the situation, and (d) the worry to being stranded in an uncomfortable situation. Based on the definitions (cf. Table 1) of range anxiety, Table 2 list the attributes that can be used to characterise the phenomenon.

Furthermore, the *stimuli* that evoke range anxiety seem to be rather settled (a perception/experience) as well as the cause for the phenomenon (limitations in the batteries and the availability of recharging possibilities) (cf. Figure 1).

However, the manifestation of range anxiety, i.e., its symptoms, is rather unknown. Today, reports suggest *behavioural* effects (re-planning activities, avoidance of usage etc.) and *emotional* effects (concern, worry, etc.), however the *physiological* (sweaty palms, dizziness, butterflies in stomach, shortness of breath, shaky hands) and *cognitive* effect (stress, etc.) are not elaborated upon in great detail (cf. Figure 1). The mediating factors such as personal beliefs are also rather unknown.

Interestingly, there are a number of reports, which suggest that the current range of EVs matches the usage patterns of most drivers but nevertheless does not match their expressed demand (Sonnenschein, 2010). That is, it appears that "range anxiety" emerge even though it is statistically shown (Sonnenschein, 2010) that the EVs a sufficient range for the typical usage pattern.

In fact, the vast majority of all trips are shorter than the range of the first EVs that hit the market. Hence, one could argue that range anxiety is not based on rational reasoning; rather it is mediated by emotion. Thus, as Sonnenschein (2010) puts it: "the problem is not *range* but range *anxiety*"(emphasis added).

One issue with range anxiety is that there is not a considerable amount of scientifically published material investigating the phenomenon, and those that do exist provides a somewhat contradicting description.

A report by Wellings et al., (2011) for instance suggests that range anxiety were 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) that pre/post trials have relieved that drivers are over-cautions when planning journeys and that range anxiety can *increase*. This may be explained by the findings by Carol (2010), namely that the degree to which a driver is willing to discharge the EV battery depends on the driver's personal level of comfort.

TABLE 2. Characterisation of range anxiety

Attribute	Descriptions	Reference
Dynamic	Change over time, and in intensity or frequency	Wellings et al. (2011), Morton et al., 2011
Subjective	The same situation is experienced in different ways by different people	Caroll (2010)
Temporal	Could change with exposure/it is assumed that it can be aided with new ITS technology	Sonnenschein, 2010; Taylor (2009); Morton (2011)
Emotional	It is a fear, belief, concern, worry	Agassi (2009); Tate, Harpster, & Savagian (2008); Philip & Wiederer 2010; **Taylor (2009)**
Object related	Its existence related to the abilities of the EVs	Brady (2010)
Experience	It can be experience while in the car	Brady (2010); Kurani, Turrentine, Sperling, (1996); Golob & Gould, (1998),Wellings et al. (2011)
Perception	It can be a perception one have of EVs	Lane & Potter, 2007
Hypothetical	The situation may or may not happen	Philip & Wiederer 2010
Future-oriented	It is a worry for a situation that may happen in future	Philip & Wiederer 2010

Pearre et al., (2011) report on a trial by Turrentine (1994) who identified how much extra range drivers needed to feel confident that they would reach their destination. The study relieved that they needed a "range buffer" of about 20 miles. This finding are similar to the studies by Frank et al. (2011) and Carol (2010).

Carol (2010) explains: "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 … [o]nly 7% of journeys were undertaken when the battery was showing less than 50% state of charge". The trend suggests that users begin to modify their driving style as the vehicle state of charge reduces to less than 50% (Caroll, 2010). Similarly, it is reported that: "the EVs drivers recharged the car even if the car was half full" (Link:15).

Franke et al. (2011) continues to note: "results show that users reserve a substantial buffer in the range they are willing to utilize. Within the sample users were only comfortable with utilizing a mean average of 82 percent (SD = 11 per cent, Q1 = 76 per cent, Q3 = 90 per cent) of the range that they achieved under daily conditions. Interestingly, there was a moderate relation between the tendency to actively test range ("I deliberately tried to exhaust the range in order to see how far I could go with the MINI E" at T2) and the acceptance of higher utilization of range resources. Thus, helping the user explore the range might also promote the use of available range resources." (Franke et al., 2011).

However, what is notably lacking is an elaboration on whether or not these findings are due to range anxiety or is just a cause of daily habits since what is being reported are the quantitative findings (driving patterns) rather that the qualitative (experience and perceptions of drivers).

It should be noted that many of the studies of range anxiety have been reported in the context of surveys of the publicly available charging network. Philip & Wiederer, (2010) reports: "The availability of charging infrastructure is a barrier to large scale deployment if intertwined with range anxiety. Public charging infrastructure is a means of addressing range anxiety, with EV users having the opportunity to access public charging infrastructure at times when they are running low on charge. The linkages between range anxiety, availability of charging infrastructure and consumer willingness to change their behaviour to match battery & charging availability constraints are interesting and are likely to vary across cities".

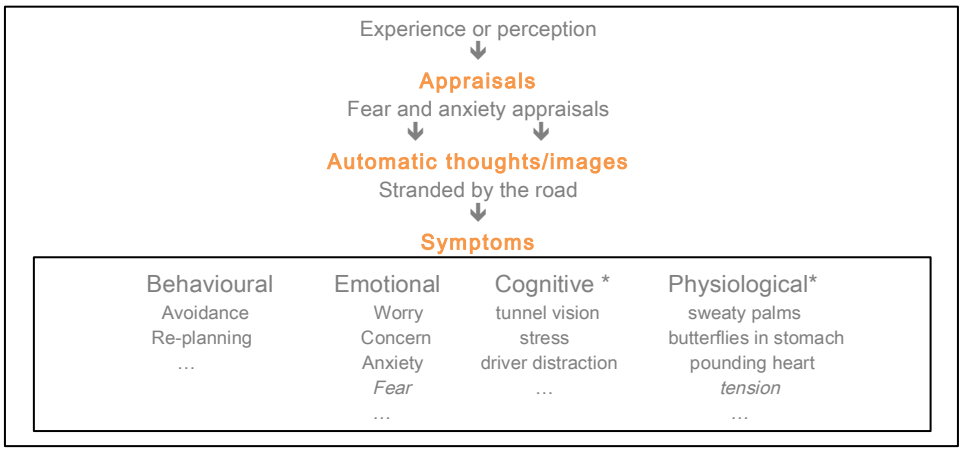

FIGURE 1. Initial theoretical range anxiety model. *Dimensions yet to be confirmed in empirical studies.

3. Current market trends to limit range anxiety

Strategies to prevent range anxiety presented in popular science

In addition to the rather limited scientifically published material on the concept "range anxiety", there are many different market trends to limit range anxiety, suggesting there are more to the concept than currently published. There is a large community discussing range anxiety on the Internet, including press realises, news magazines and blogs, etc.

In the following, some of the approaches promoted by, for instance, Ford, GM, and Nissan are presented. The approaches mentioned have been identified via Internet searches (e.g., Google). In general, the approaches can be classified according to the underlying principle of the service (cf. Table 3).

It should be noted, that the listed approaches in Table 3 are typically presented as the cure of range anxiety, however, in the presented material, it has not been elaborated upon *how* they may actually reduce range anxiety, nor to *what effect* or *why*. Although, the presented approaches are not scientifically proven to reduce range anxiety they provide interesting insights regarding the phenomenon. The listed services in Table 3 are by no means intended to be exhaustive.

Give suggestions on actions to best extend your range

To minimise the car energy usage can be one successful way of extending the range of the EV. For instance, MapQuest is an on-board screen display launched in the Ford Focus, which includes a feature "can I get there?" (Link 2). If the driver enters a destination out of the EV's range, the interface provides suggestions on how to best extend the range (Link 3). For example, the system can suggest lower speed roads and reroute the trip in order to save energy. It also offers ideas such as shutting off the air conditioner (Link 4).

Similarly, the Nissan Leaf displays how much extra range the EV would have if the climate control system were turned off (Link 11). In addition, an "ECO" mode encourages light-footed driving, and includes regenerative braking (the car slows more dramatically when the driver takes his foot off the accelerator)(Link 11).

TABLE 3. Current strategies to limit the *situation* in which the driver experience range anxiety due to lack of energy

Underlying approach	Service
Inform about the situation	Inform about current range and status of the EV
Provide strategies to prevent the situation	Award good behaviour
	Provide warnings on low battery
	Give suggestions on actions to best extend your range
	Pre-heat the car while charging
	Remote access of the vehicles status
	Social competition
	Energy usage information
	Provide accurate and transparent information
Provide solutions to solve the situation	Information about nearest charging station
	A gasoline engine as a back up
	Use a second battery as back up
Limit the risk for the occurrence of the situation	Inform about areas reachable by the EV
	Suggestions base on personalised driving pattern
	Fast charging abilities
	Simulate you expected range usage before the buy
	Improve the range with new technology solutions
	Provide as many publicly available charging station as possible
	Charge the EVs at a interesting place
Eliminate of the consequences of the situation	Rescue in case of out of energy
	Provide a "loan car"

Informing about current range

The estimated range of the vehicle is argued to be one of the most critical pieces of information to the driver (Wellings et al., 2011). When the estimated range information is combined with battery state of charge, the driver can be able to get an understanding of the current range of the EV..

Award good behaviour

Another approach is to teach/make the driver to drive in a way that extends the range of the EV. Nissan Leaf includes features such as a "how am I driving" display. If the vehicle is being driven conservatively, digital "trees" will "grow" (up to three), and the numeric display will show greater range (Link 11). That is, the EV could rate the driving behaviour on a scale from "Zippy to Zen." (Zen means a better range). Similarly, "[i]nstead of the green leaves that display on the Ford hybrids to reward good performance, the electric uses blue butterflies (which accumulate to show your "range surplus" beyond the next charger)"(Link 2).

Pre-heat the car while charging

To extend the range of the EV, the driver can utilise the power provided by the electric grid while plugged in. With the aid of, for instance, a cell phone, the driver can start or stop the charge, or pre-heat or cool the vehicle while it is still plugged rather than using the battery after they hit the road (Link 2).

Inform about areas reachable by the EV

Just as other brands, the Nissan Leaf provides continuously updated information regarding the distance to the next charging station (Link 2). In addition, the information is visualised as a white circle for an area easily reached, and a grey circle for a larger area but still well within the vehicle's capability in the navigation system (Link 11).

The idea is that "as the navigation screen fills with more and more symbols indicating locations of charging stations, driver confidence will rise. With many charging stations located in parking lots, the EV commuter will be assured he can add more side trips to his normal daily routine"(Link 11). The circles in the navigation system are also expected to be confidence builders (Link 11).

Similarly, the myFord Touch provides drivers with different means to check their remaining charge, and with help of GPS the system can determine weather the driver can make it to the remaining destinations (6). Furthermore, Celadon Applications (Link 13) has "built an application that can aggregate all sorts of data, including topographical, weather forecasts, terrain, altitude, temperature, drivetrain performance, torque, and RPM, among other things, and bundles all that information into an interface that alerts electric vehicle drivers to how much range their cars truly have at any given second". It claims to be the first application range calculator, which relies on a physics simulator instead of approximations or, as they say, "other tricks".

Suggestions based on personalised driving patterns

There are EVs, which can adjust individual drivers' range based on what it knows about their driving style, thus potentially providing a more accurate range estimation (Link 2). For instance, in the Nissan Leaf the drivers are classified into categories ranging from "zippy" to "zen", this information is then used to make more accurate range calculations (Link 6).

Warnings for low battery

It is reported that Nissan Leaf has a sophisticated version of the "low fuel" warnings on gasoline engine cars (Link 11). That is, with approximately 19 to 20 km of range remaining, a low-battery warning will come on, and top speed is reduced by a complex algorithm and continues to drop as the vehicle is driven.

Information about nearest charging station

Most typically, it is reported that there is a feature included in the navigation system which displays the nearest charging station. For instance, the navigation software could tie an alert to the distance to a station vs. a programmed destination, if the trip is beyond the EV range (Link 11).

Rescue in case of breakdown

It is reported (Link 11) that the Nissan Leaf will have a free roadside assistance for two years, meaning that the driver never will be stranded. In detail, Nissan's service provider, will flatbed the Leaf but, as volume increases, have the ability to add roadside charging. In addition, there are reports (Link 8) on a loaner car plan: "The loaner

car plan would allay 'range anxiety' concerns among electric car buyers". Others report that "Nissan is planning to implement a sort of "insurance" where a driver pays $200 a year to cover recovery if the Leaf runs out of "juice" and the cost of the first service (6 months service)".

Remote access to the cars status

When the Leaf is plugged in, while the driver is at work or shopping, there is a smart phone application which will let the driver know the status of the EV. For instance, if the charge cord becomes unplugged, the phone displays a notice (Link 11). Similarly, it is reported (Link 7) that the Volt includes remote access that that enable drivers to control certain vehicle functions such as scheduling battery charge times, viewing whether or not the vehicle is plugged in, checking voltage at a charger, and getting text notifications of interruption or completion of a battery charge.

Fast charging abilities

There are also reports of fast charging battery pack, which can charge from under 20% up to 80% in less than 30 min (Link 11). There are currently two approaches to fast charging and standards are being developed.

Social competition

It has been reported that Nissan Leaf will include the "Carwing" system which allows drivers to compare their driving habits to those of other Leaf owners (Link 9). The system allows to connect every Leaf vehicle to a network, keeping track of data on each car: miles driven, charge remaining, miles per charge, and so on. The network allows the drivers to see how their driving stacks up against their peers (including rewards for good driving) and thereby encourage economical driving to extend range.

A gasoline engine as a backup

After 40 miles of all-electric driving, a gasoline engine kicks in to recharge the batteries on the fly. (Link 8, 12). It is further reported that General Motor calls it a "range extender" and is said to address 'range anxiety' (Link 12).

Use a second battery as a backup

Drivers report of the security a battery swap would involve: "moment came when I concluded that the fastest way to gain a full charge would be to simply swap out the battery, much like swapping computer batteries during a long flight. Here, the car industry had made a conceptual error: regarding the battery as a fixed unit within the car, which could not be removed easily or quickly" (Link 15).

Simulate your expected range usage before the buy

One part of range anxiety is related to the fact that you do not know if you would experience problems with range (Link 10). To solve this issue, a specific simulation application iEV has been promoted (Link 10). The application helps drivers to simulate the normal driving with any electric car configured in the application. As they explain: "For example, if you want to buy a Nissan Leaf, just enter the data for this EV and simulate it for several months, day by day. You will know exactly, whether this car is for you or not. Doing this the app takes into account your region, your speeds, your accelerations, your distance" (Link 10).

Show available charging stations

Coulomb technologies has developed an application which lets EV drivers not only locate charging stations, but also determine whether they are available, what voltage they deliver, and whether they are fee-based or free (Link 1). In a similar manner, Google Maps will show the nearest EV charging dock. Another idea is portrayed in the application Plugshare (Link 17). They explain: "If I live in Silicon Valley and have an EV charging dock, and a friend is getting one installed in San Francisco, we should be able to share those charging stations".

Charge the car at an interesting place

Pioneer is looking at mapping algorithms that will take into account the kind of tasks consumers might accomplish during the wait (Link 19).

Improving range with technology solutions

Another smart solution is to introduce heated seats and steering wheel to reduce need for cabin heat, and that way, have more power to extend the range of the car (Link 11). In addition, a battery "blanket" could keep the battery pack warmer, so it can deliver more of its charge (Link 11)

Energy usage information

Many of the EVs provide the driver with information about how much energy you take out

of an EV at any given time (Welings, 2010). This information provides instant feedback on the driving style.

Providing as many publicly available charging stations as possible

There could be a symbolic value to being able to see and be reminded that there exist places where it is possible to charge the EVs. There is a symbolic value of seeing EV and EV charging stations. (Weiller, 2011).

Provide extra range beyond the current need

"We have analysed the distance driven daily, but actual vehicle design would need to leave some margin of surplus range over the needed driving. This is to prevent an error or an unplanned side trip from stranding the driver, and to avoid driving with little energy remaining in the battery (Pearre et al., 2011)

Provide more accurate and transparent information

There are suggestions (Link 18) that manufacturers need to communicate honestly and transparently about the realities of range so that drivers' expectations are set appropriately.

4. Current Strategies to Measure Range Anxiety

Elaboration of how one measure anxiety and range anxiety

Anxiety, in general, is often measured with the aid of questionnaires and rating scales. According to Zeidner & Matthews (2011) one needs to detect the following four aspects to be able to capture the characteristics of anxiety:

- The anxiety producing stimuli, i.e., the situation as such
- The response channel and reaction to the anxiety
- The frequency and insensitivity of anxiety
- The styles of coping with the anxiety (avoidance, do not drive far, extra battery etc.)

Most often when one measures anxiety one focuses on cognitive and emotional experience, and less on the situation specific antecedent elicitation anxiety or the dynamic fluctuations of anxiety (Zeidner, Matthews 2011.)

Range anxiety

The methods employed to study EVs includes, but are not limited to (Morton et al. 2011):

- Stated preference/revealed preference
- Questionnaires/attitude surveys
- Games and simulations/mixed methods
- Qualitative surveys
- Pre/post trails (interviews, questionnaires, data logging)
- Agent based modelling
- Geo-demographic modelling and market segmentation

In addition, Cocron et al., (2011) have developed a framework for user evaluation of EV for the purpose to capture the acceptance and suitability of EVs in everyday mobility. The framework consists of 4 pillars: mobility, human–machine interaction (HMI), traffic and safety implications and acceptance. The framework utilises a combinations of methods such as data loggers, travel/charging diary, interviews, trip decision games, and conjoint analysis.

Range anxiety, in particular, 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. Also attitude surveys (e.g., Lane & Potter, 2007) have been used to identify prospective costumers perceptions.

Interestingly, despite being identified as the main barrier for the success of EV, range anxiety has only being studied as part of a larger study. There is no study targeting solely range anxiety. However, the studies that did capture range anxiety have targeted the following aspects thereof:

- Behavioural aspects: real world trials which identify driving patterns and possible avoidance behaviour

- Perception of range anxiety: surveys which identify attitudes of range
- Psychological aspect: surveys which capture emotional response

Potential concerns when measuring range anxiety

Studying range anxiety is not trivial. There are a number of different issues which need to be considered while measuring range anxiety. These aspects could have major impact on the outcome of any empirical study regarding EVs.

The perception and experience change over time, which may impact the results. Caroll (2010) makes the following reflection: "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. " Hence, the following issue need to be considered:

- The length of the study may affect the drivers perceptions/experience of the EVs

Furthermore, it has been noted that the typical test users of EV can be classified into early adopters, that is, "EV enthusiasts". Characterising for these early adopters of EVs is that they are more positive and have a higher interest in the EVs (Wellings., 2011). This leads to the following issue:

- The drivers are not likely to be critical to the proposed services and possess a "pioneer personal trait"

In general it is difficult to capture anxiety and emotional state retrospectively.

- Drivers may have difficulties to express their emotions
- A retrospective notion of range anxiety may be different compared to the actual experience

In addition, when considering range anxiety one needs to consider the difference between leasing an EV, owning the EVs, using for private or company purposes. Thus, the following needs to be considered:

- The context of use. The difference of being a private household compared to a car pool.

5. Conclusions

Conceptualising range anxiety

The material reviewed in this report highlights a number of different characteristic dimensions of range anxiety, which can be used as a starting point when identifying enablers for limiting range anxiety.

Within this report, range anxiety is defined as a perception or experience of not being able to reach ones destination in an EV.

It can be predicted that range anxiety will become more and more present as the number of EVs increases. This is particularly evident in the high number of approaches suggested to limit range anxiety.

Surprisingly, there is little published research on the effect and how the approaches will actually reduce range anxiety. In general, it is suggested that an extended range will reduce range anxiety.

The typical approach for measuring range anxiety includes pre/post trials and attitude surveys. However, it is suggested that alternative methods are needed to capture all the dimensions that range anxiety manifest itself.

Further studies

There are a number of research questions and issues, which need further investigations. For instance, the following questions have been identified:

- Is there a physiological dimension of range anxiety (sweaty palms, pounding heart etc.)?
- What is the dynamic and temporal nature of range anxiety?
- Is range anxiety a matter of actual distance, or a problem measuring how much battery power there is?
- How does the conceptual/theoretical model of range anxiety look like? That is, what are the relationships between range anxiety and charging infrastructure, or other information variables?
- How can range anxiety be measured?

These questions may have implications for the abilities of suggested services to truly reduce range anxiety and for how the phenomenon should be measured/evaluated.

Subsequent reports will investigate range anxiety in more detail and present empirical findings and alternative methods for evaluating range anxiety.

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