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Charged up with peace in mind: Unraveling the factors of range anxiety among norwegian electric vehicle drivers

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ABSTRACT

Range anxiety and its associated factors are crucial for designing effective solutions to enhance the Electric Vehicle (EV) user experience. The present study is based on a survey of 1,005 EV drivers in Norway. It aims to provide insights into the perception of range anxiety in a country with well-developed electric mobility. We contribute to the state-of-the-art by exploring the concept of range anxiety based on eleven potential explanatory variables describing EV adopters' driving experience, charging-related user experience, psychological characteristics, and socio-demographics. Our analysis showed that the longer the EV driving experience, the greater the perceived ease of charging and charging flexibility, the lower the range anxiety will be. Further, stronger control beliefs over EV's charging state and willingness to take risks relate to lower range anxiety. Additionally, being younger and being female are associated with lower range anxiety among EV drivers. However, perceived helpfulness of charging guidance, technology openness, and settlement size of EV drivers are not significantly associated with range anxiety. Our study highlights the importance of providing situation- and user-oriented charging information, a smooth and easy-to-understand charging process, and the need to support EV drivers who are less experienced, older, and routine-based.

1. Introduction

The widespread adoption of electric vehicles (EVs) is an important step towards more sustainable mobility. However, one of the remaining key barriers hindering the acceptance of EVs is the issue of range anxiety – the concern that an EV's battery may not have sufficient charge to reach the desired destination or complete a planned journey (Adnan et al., 2017; Tate et al., 2008). Studies have shown that range anxiety can lead to suboptimal charging practices, such as frequent and unnecessary top-ups to keep the battery full, which in the case of uncoordinated charging can strain the grid and undermine the environmental benefits of EVs (Franke & Krems, 2013; Morrissey et al., 2016). As the global EV market continues to grow, with sales expected to reach 31.1 million units and a market share of 35 % by 2030 worldwide, understanding and addressing range anxiety has become increasingly important (International Energy Agency, 2024).

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Range anxiety is a multifaceted phenomenon that is influenced by several factors, including psychological and individual characteristics of EV drivers (e.g., Franke et al., 2012; Philipsen et al., 2019; Rainieri et al., 2023), human–machine interaction with in-vehicle applications (e.g., Eisel et al, 2016; Rauh et al., 2017), as well as charging infrastructure (e.g., Neubauer & Wood, 2014; Mashhoodi & van der Blij, 2021), and battery capacities of EVs (e.g., Noel & Sovacool, 2016). Simultaneously, range anxiety can significantly impact the driving and charging behavior of EV drivers, with important implications for the overall efficiency and stability of the electrical grid (Neubauer & Wood, 2014). However, there is a lack of research on how perceived daily charging routine, along with a combined consideration of demographic and psychological factors, together with charging-related variables, could relate to range anxiety.

Our study aims to provide empirical insights about factors related to range anxiety based on a large-scale survey with $N = 1,005$ EV drivers in Norway. The high EV adoption level and well-developed electric mobility of the Norwegian market (International Energy Agency, 2024; Statista, 2023) enable us to examine range anxiety among actual EV drivers with diverse experience levels and charging behavior types. By considering EV adopters' driving experience, charging-related user experience, psychological characteristics, and socio-demographics, we aim to understand how these factors can explain range anxiety. Our analysis provides new insights into the several personal, behavioral, and contextual aspects to develop targeted strategies that can help address range anxiety among different types of EV drivers and driving circumstances.

2. Literature Review

While the range of most EVs already meets approximately 95 % of typical driving needs (Pearre et al., 2011), the availability of extended EV ranges (Noel & Sovacool, 2016; Pevec et al., 2019) and widely expanded charging infrastructure (Mashhoodi & van der Blij, 2021; Neubauer & Wood, 2014) are important factors in alleviating range anxiety. On the other hand, researchers argue that factors related to range anxiety are not only technical in nature. The discussion about range valuation should therefore also include individual and psychological factors (Noel & Sovacool, 2016; Rauh et al., 2015). Yet, given that behaviors, expectations, and attitudes are challenging to influence, increasing the performance of batteries and chargers is often considered a more feasible and easy approach to address range anxiety (Noel & Sovacool, 2016). Nonetheless, as the expansion of the charging network and increase of battery capacity is expensive and exhausts many resources (e.g., financial, ecological, grid capacity), investigation of the individual characteristics related to range anxiety has become evident.

According to previous research on range perception (Franke et al., 2012; Franke & Krems, 2013; Rauh et al., 2015), range anxiety is defined as a domain-specific type of psychological stress (Lazarus & Folkman, 1984). Based on this theory, anxiety occurs when an individual feels threatened to be unable to cope with a situation in certain settings with available resources and capabilities. Hence, EV drivers first evaluate whether an encountered situation within a trip setting could lower the available range more than planned or would be comfortable for them. In the second step, they assess different solutions, such as searching for available charging stations, adjusting the air-conditioning, or decreasing driving speed (Rainieri et al., 2023). If none of the undertaken actions solve the situation, range anxiety will increase. Following Noel et al. (2019), past research has defined range anxiety from three perspectives. Technically, range anxiety occurs when the battery capacity restricts the achievable driving range. Psychologically, range anxiety is an irrational concern about the EV's battery level dropping below a certain percentage, or unwillingness to adapt one's driving behavior to the EV's range limitations (e.g., by making a charging stop). Range anxiety can also be a rhetorical reaction that hides deeper underlying issues related to EVs' adoption in general.

The accumulated body of literature shows that perceptions and handling of range anxiety are closely related to the psychological characteristics of EV drivers. Researchers have indicated that higher technology acceptance (Philipsen et al., 2019), stronger control beliefs (Franke et al., 2012; Philipsen et al., 2019) as well as comfort with a low battery level (Franke et al., 2016) relate to decreased range anxiety. Earlier findings of Philipsen et al. (2018) indicate that the higher the willingness to take risks the higher the preferred recharging frequency and the readiness to postpone charging until the state of charge (SOC) is low. Moreover, Pevec et al. (2019) indicated that EV drivers with high risk-seeking tendencies accept crossing greater distances or using all their remaining range to reach the next charging station. Although researchers have expected people with high risk-seeking tendencies to be less anxious about their range, a later study showed a positive relation between risk-taking and range anxiety (Philipsen et al., 2019). The findings showed that people with a higher risk aversion tend to avoid trip settings where the battery is running too low in the first place, which in turn keeps their range anxiety level low. However, these studies examine mainly non-EV drivers, and they solely considered a limited range of potential factors associated with range anxiety, such as driving range preferences and psychological variables.

Demographic factors are also found to be associated with range anxiety. For example, Thorhauge et al. (2024) observed that female EV drivers and individuals over 50 years of age are more sensitive to range anxiety. Yuan et al. (2018) found that EV drivers who are male or young (below 33 years old) react to range anxiety by trying to approach recharge points quicker while eventually violating traffic norms, which is, therefore, considered risky behavior. Pevec et al. (2020) identified that EV drivers living in rural/smaller settlements are more inclined to accept greater distances between charging stations than in urban/larger settlements. Thereby, the preferable distance between two neighboring charging stations has been used to define range anxiety. Meanwhile, despite interesting findings about the relationship between range anxiety, demographics and psychological characteristics of EV drivers, there is little research concurrently examining their relationships.

Moreover, a substantial body of studies has shown that longer driving experience and stronger range coping skills are associated with reduced range anxiety among EV drivers (Franke & Krems, 2013; Franke et al., 2017; Pevec, et al., 2020; Philipsen et al., 2019; Rauh et al., 2017). Some of the studies are based on field trials to validate the effect of practical experience (e.g., Franke et al., 2017; Rauh et al., 2020), while others compared EV drivers with internal combustion engine (ICE) drivers to examine differences in perceived range stress between active and potential users (e.g., Pevec et al., 2020; Philipsen et al., 2019). Rauh et al. (2015) argued that EV drivers first evaluate their available range buffer against a preferred safety buffer and then consider their coping skills to face a range critical situation. Thereby, the smaller the difference between available and preferred remaining range and the higher the coping skills (e.g., factual knowledge about strategies for economical driving and factors influencing range), the lower the threat perception and hence the resulting anxiety. In addition, lower range anxiety is also related to reliable information about the remaining range (Eisel et al., 2016; Franke et al., 2012; Franke et al., 2016; Rauh et al., 2017), SOC (Franke & Krems, 2013; Sankaran et al., 2020; Walsh et al., 2011), and helpful range-saving suggestions (Musabini et al., 2020; Rauh et al., 2015; Rauh et al., 2020). However, these studies tended to include small samples of EV drivers with a limited distribution of demographics, which restricts generalizations of their findings to the overall population of EV drivers. Further, due to the field study setting, the researchers could have overlooked the contribution of individual EV driving experience in real life and its role in range anxiety formation.

In summary, previous research has found that a mixture of demographic, psychological, socio-technical, and vehicle-related factors are associated with range anxiety (Rainieri et al., 2023), and that EV drivers have different coping abilities to adapt to a diverse range of critical situations (Franke et al., 2016; Rainieri et al., 2023). Past research has also briefly discussed and distinguished range anxiety by low fill level, insufficient range, erroneous self-assessment of range, and fear of breakdown (Philipsen et al., 2019).

2.1. Present study

To contribute to the existing literature about range anxiety, our study aims to provide empirical insights from Norway which is one of the frontrunners worldwide in terms of electric mobility. With our EV-population-based survey, we aim to investigate factors associated with range anxiety. For that, we include in our analysis factors describing EV drivers' socio-demographics, driving experience, charging-related user experience, and psychological characteristics. We explore different predictors in terms of range anxiety, which we calculate based on the average range anxiety values across five trip settings.

Earlier studies (e.g., Eisel et al., 2016; Franke et al., 2016; Rauh et al., 2020) used restricted samples with low representativity and had limitations in terms of study environment and considered variables. However, their findings serve as a theoretical basis for the current research to test them in another study environment, and setting, and combined with a wider array of explanatory variables. The conceptual framework of our study is depicted in Fig. 1. The figure displays EV driving experience, charging-related user experience, and psychological characteristics as well as the respective hypotheses about their relation (solid line) to range anxiety. Also, we added socio-demographics as control variables to analyze their association (dotted line) with range anxiety.

In Table 1, we present the research questions (RQs) and respective hypotheses, to test findings of previous literature as well as to examine new factors potentially related to range anxiety. As EV driving experience improves coping skills with limited range and reduces anxiety (e.g., Franke & Krems, 2013), we hypothesize that drivers with longer EV driving experience perceive less range anxiety (H_1). Since in-vehicle information and recommendations help to reduce range stress (e.g., Eisel et al., 2016), we hypothesize that perceived helpful charging guidance (e.g., in car or mobile apps) relates to lower range anxiety (H_2). Based on the association of low range tolerance with less discomfort regarding range (Franke et al., 2016), we propose that ease of charge at low SOC relates to lower range anxiety (H_3). As the availability of charging opportunities links to less anxious charging behavior (e.g., Rainieri et al., 2023), we assume that the easier it is to charge less frequently than at present, the lower the range anxiety (H_4). Based on the association of perceived ease of use and actual (satisfied) use (Davis, 1989), we hypothesize that with perceived ease of charging process, range anxiety decreases (H_5). As technology interest and commitment correlate with less range stress (e.g., Philipsen et al., 2019), we suggest that EV drivers with higher openness towards new technologies and innovations perceive less range anxiety (H_6). Because risk-

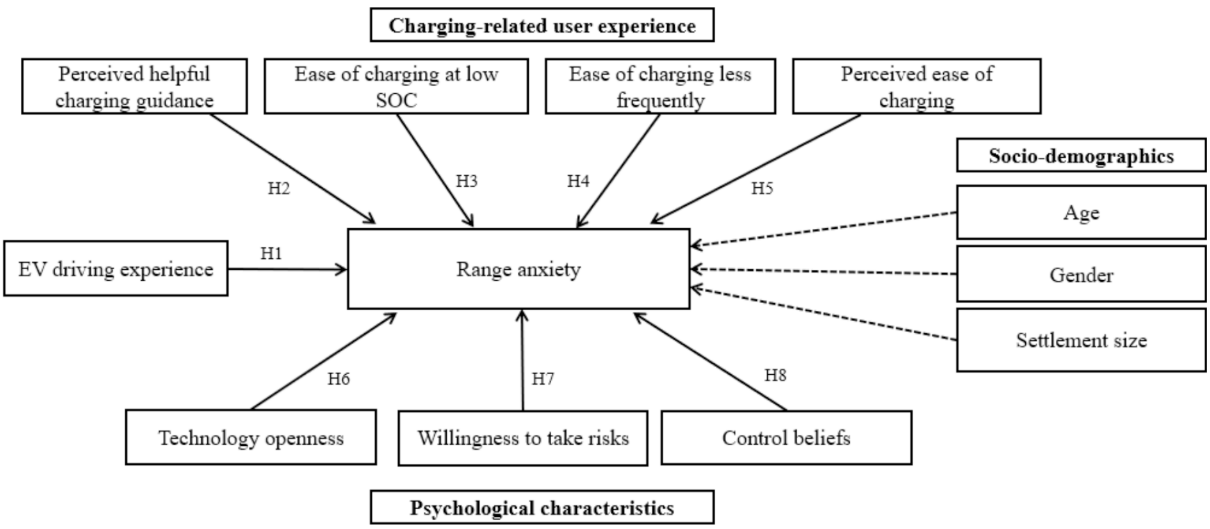

Fig. 1. The Conceptual Research Framework.

Table 1
Research Questions and Hypotheses.

Literature reference	Variable	Hypothesis	Definition
RQ_1: How is EV driving experience associated with range anxiety?			
Franke & Krems, 2013; Franke et al., 2017; Pevec, et al., 2020; Philipsen et al., 2019; Rauh et al., 2017	EV driving experience	H_1	EV drivers with longer driving experience perceive less range anxiety.
RQ_2: How is charging-related user experience associated with range anxiety?			
Eisel et al., 2016; Franke et al., 2016; Rauh et al., 2015	Perceived helpful charging	H_2	Perceived helpful charging guidance is associated with lower range anxiety.
Franke et al., 2016	Easy to charge at low SOC	H_3	Feeling easier to charge when the battery is low is related to lower range anxiety.
Franke & Krems, 2013; Rainieri et al., 2023	Easy to charge less frequently	H_4	The easier it is to charge less frequently than at present, the lower the range anxiety.
Davis, 1989	Perceived ease of charging	H_5	Higher perceived ease of charging is associated with lower range anxiety.
RQ_3: Which psychological variables of EV drivers relate to their range anxiety?			
Franke et al., 2012; Philipsen et al., 2019	Technology openness	H_6	Higher technology openness is related to lower range anxiety.
Philipsen et al., 2019	Willingness to take risks	H_7	There is a positive relationship between willingness to take risks and range anxiety.
Franke et al., 2012; Franke et al., 2016; Franke et al., 2018	Control beliefs	H_8	Higher control beliefs over the range situation relate to lower range anxiety.

seeking drivers are more likely to run battery empty and face anxiety situations (Philipsen et al., 2019), we suggest a positive relation of higher willingness to take risks to range anxiety (H_7). As control beliefs over the remaining range improve the coping skills with lower range (e.g., Franke et al., 2012), we hypothesize that control beliefs over EV's charging state relate to lower range anxiety (H_8).

Overall, the present study targets to develop novel knowledge that will improve our understanding of range anxiety. Particularly, we are interested in how the EV driving experience, perception of charging routine, and psychological background relate to range anxiety. Identification of factors associated with less range anxiety could help to develop effective strategies to reduce such anxiety, which could substantially contribute to the balanced use of the charging infrastructure and battery.

3. Method

3.1. Survey and participants

This work is based on a survey with 1,005 EV drivers conducted from January to February 2024 in Norway. The EV drivers were recruited by Norstat which is a market research panel aggregator company. Being Norway's largest consumer panel, it consists of over 120,000 active participants. All respondents received 10 Norstat coins as a reward for completing the survey, which can be spent or donated in the Norstat store. In total 1,054 EV drivers were contacted of which 1,005 respondents completed the survey. Due to the lack of information on the true distribution of EV owners in Norway, the sample was obtained randomly based on the national distribution of gender, age, and geography, yielding a robust data set. The sample exclusively included individuals who indicated that they possessed an EV. Our sample had an average age of 46.5 years ($SD = 16.7$, MIN = 18, MAX = 89) of which 47.76 % were female and 64.4 % had a university degree. In addition, 66.9 % were employed, and 91.34 % drove an EV that they owned by themselves or that was owned by a family member. In terms of representativity of the Norwegian population, we compared the sample characteristics to those of the population: Approximately 50 % of Norway's adult population is female (compared to 47.76 % in our study), whereas 36.9 % of all Norwegian citizens possess higher education (compared to 64.4 % in our study) which can be explained by the overall higher education level in the Norwegian EV driver population (Bjørge et al., 2022). The province Akershus has the highest population in Norway compared to the remaining provinces which is mirrored in our sample with the highest percentage of respondents (15.42 %), whereas Finnmark is the least populous province in Norway, constituting the smallest share in our sample (0.50 %) (Norwegian Government, 2022).

3.2. Questionnaire and data

Appendix 1 illustrates the part of the questionnaire used in the present study. The variables considered in the regression analysis are described in detail in the following.

3.2.1. Perceived range anxiety

We measured perceived range anxiety in five different trip settings using a seven-point Likert scale, ranging from 1 (not at all) to 7 (to a great extent). We asked respondents to evaluate how much anxiety they experience regarding the range of their EV in the following trip settings: for spontaneous trips, long-distance journeys, unknown routes, in case of unexpectedly high traffic congestion, and extreme weather conditions (e.g., high or low temperatures). Since for these five variables, participants could choose the option "I don't know", the value was then considered missing. The five settings were chosen due to their frequency in EV routines, influence on EV usage and range anxiety. We measured range anxiety in spontaneous trips, to understand if EV drivers feel comfortable adapting their behavior to avoid limited range, for example by using safety buffers (Nilsson, 2011). We included long-distance journeys to measure how comfortable EV drivers are about the need to consider and plan recharging on a longer drive (Roccotelli et al., 2023). As knowing the route is critical for EV drivers to estimate the need to recharge and the distance to a charging station (Smuts et al., 2017), we measured how much range anxiety EV drivers perceive on unknown routes. Driving in intensive traffic (Jonas et al., 2022) or with extreme ambient temperatures (Reyes et al., 2016), increases EV's energy consumption and limits range capacity. To evaluate how much inconvenience handling these consequences would mean for EV drivers, we considered range anxiety in both situations.

3.2.2. EV driving experience

For measuring EV driving experience, we asked our participants to indicate how many years they have been driving an EV. We used that as an indicator of their practical EV-related knowledge. In the past, the EV experience has often been measured based on the existence of any previous experience with EVs (e.g., Pevec et al., 2020) or during a field trial (e.g., Franke et al., 2017). As the first electric vehicles have been available on the market since 2008 (Vynakov et al., 2016), we removed answers that were above 15 years of experience.

3.2.3. Perceived charging guidance

For perceived charging guidance, we asked participants to indicate how helpful they perceive the guidance (e.g., by their EV or charging app) in performing charging successfully. Also here, we used a seven-point Likert scale, ranging from 1 (not at all) to 7 (to a great extent). We included this variable to assess if the quality of perceived charging guidance in EV drivers' daily routine has any association with range anxiety in our study setting. Our question is based on the findings from the literature that helpful in-vehicle information and recommendations are related to less range anxiety (Eisel et al., 2016; Franke et al., 2016; Rauh et al., 2015).

3.2.4. Ease of charging at low SOC

To measure the ease of charging at low SOC, we asked our respondents to indicate how comfortable they find it to start charging at a low SOC (below 30 %). The variable was measured on a seven-point Likert scale, ranging from 1 (not at all) to 7 (to a great extent). We included this variable to evaluate the feeling of comfort to start charging at the lower battery level. Low SOC is perceived differently depending on the EV's battery capacity: the higher the capacity, the higher the remaining range at the same SOC. According to Franke et al. (2016), the discrepancy between the comfortable range and remained range is related to the perceived level of range stress. To address this discrepancy and indirectly also consider battery capacity through individual perception of low SOC, we intend to test the association between ease of charging at low SOC and range anxiety.

3.2.5. Ease of charging less frequently

To measure the ease of charging less frequently than at present, we asked survey participants to evaluate how easy it would be for them to charge less frequently if they wanted to. The variable was measured on a seven-point Likert scale, ranging from 1 (not at all) to 7 (to a great extent). By including this variable, we aim to understand the flexibility of EV drivers in scheduling their charging sessions based on the availability of infrastructure. Instead of studying the association between charging infrastructure and range anxiety (e.g., Neubauer & Wood, 2014), we focus on perceived charging flexibility determined by the state of the charging network. Availability of charging opportunities is related to less frequent charging and thus to less anxious charging behavior (Franke & Krems, 2013; Rainieri et al., 2023). In our analysis, we measure the availability of charging opportunities indirectly through the perceived feeling of flexibility. This approach enables us to consider individual perspectives on decision-making and hence, on range anxiety.

3.2.6. Perceived ease of charging

Our study contained the 2-item scale of perceived ease of charging based on the scale for perceived ease of use by Davis (1989), to measure the degree to which an EV driver believes that the charging process would be free from effort. Our scale yielded a Cronbach's alpha value of $\alpha = 0.65$, which, considering number of items and Pearson's r value of 0.47, can be considered satisfactory (Tavakol & Dennick, 2011). We included this scale to measure how an individual feeling of comfort with the charging process in daily charging routine is related to the perception of range anxiety. When an EV driver perceives the overall charging process as pleasant and comprehensible, it could be easier for them to handle situations with (unknown) impact on battery level.

3.2.7. Technology openness

We used a 4-item scale measuring technology perception. We derived this scale from the measures of innovativeness by Parasuraman and Colby (2015) indicating the propensity and readiness to adopt new technologiesscepticism$\alpha = 0.70$ and an average inter-item correlation of 0.36, which shows satisfying consistency of the scale (Tavakol & Dennick, 2011). Our rationale for including this measure is based on previous findings that technology commitment and acceptance are related to less range stress (Philipsen et al., 2019).

3.2.8. Willingness to take risks

Furthermore, we included the 1-item scale for willingness to take risks (Harrison & Rutström, 2008) to evaluate the level of risk propensity of EV drivers generally. The variable was measured on the seven-point Likert scale, ranging from 1 (not at all) to 7 (to a great extent). This question is a feasible predictor of risk-taking behavior in different domains (e.g., Bonin et al., 2007; Caliendo et al., 2009; Dohmen et al., 2011). At the same time, the individual risk attitude has been found to be related to less range anxiety (e.g., Philipsen et al., 2019), which is why we aim to test this measure in a different study setting.

3.2.9. Control beliefs

Besides, we added a 2-item belief of control scale based on perceived behavioral control by Ajzen (2002), which measures how much control EV drivers perceive over the remaining range and current battery level. The scale yielded Cronbach's alpha of $\alpha = 0.64$, which, considering number of items and respective Pearson's r value of 0.48, can be considered satisfactory (Tavakol & Dennick, 2011). By including this measure, we aim to test previous findings by Franke et al. (2012; 2016; 2018) in a different study setting. Researchers found that higher control beliefs over the range situation influence the coping of limited range, and thus the experienced range stress.

3.2.10. Socio-demographics

For control purposes, we also included variables to measure the socio-demographic background of our respondents. We considered EV drivers' age (in years), gender (male = 0, female = 1), and settlement size of EV drivers (no = 0, yes = 1) as dummy variables (village with < 1,000 inhabitants, town with 1,000 – 20,000 inhabitants, city with 20,000 – 100,000 inhabitants, big city with > 100,000 inhabitants). Thereby, the category of the big city served as a reference base. These socio-demographic indicators were adapted from the study by Pevec et al. (2020).

3.3. Analysis approach

To establish a multiple linear regression model based on range anxiety, we calculated the average of non-missing values of the five trip values. We considered the five trip items as one indicator of overall range anxiety which we use as a single aggregated dependent variable in the linear regression model. Before generating the aggregated variable, we tested the dimensional structure of range anxiety by exploratory factor analysis (EFA) and principal axis factoring method (Fabrigar et al., 1999). Dimension extraction is based on the Kaiser criterion (Kaiser, 1958), on visual inspections of the Scree plot and the Horn's parallel analysis (Horn, 1965) as well as the interpretability of dimensional loadings. The reliability of the single dimension of range anxiety was tested using Cronbach's alpha ($\alpha = 0.93$) and average inter-item correlation (0.71).

Although we collected ordinal data measuring range anxiety in five trip settings, by assigning a respective score (7 to strongly agree and 1 not at all), we transformed the ordinal scale to an interval scale with equally spaced numerical variables (Chen & Wang, 2014). Our model was controlled for required assumptions, i.e., normality, linearity, no multicollinearity, no heteroscedasticity, and normally distributed error terms (Field, 2009). The heteroskedasticity test was positive, although after further inspection we could not detect any violation of constant variance among explanatory variables. The explanatory variables had a mean variance inflation factor (VIF) of 1.27 with a mean tolerance of 0.80, which indicates no multicollinearity in the linear model (Daoud, 2017). Therefore, aligned with the required assumptions, our linear regression was considered adequate. Moreover, previous research has shown that when dealing with measures of behavior and attitudes, ordinal data are usually sufficiently robust to calculate mean scores, and standard deviation and conduct parametric tests (Norman, 2010; Sullivan & Artino, 2013).

To test the statistical significance of differences between all settings, we applied paired t-tests. We considered the Bonferroni criterion to counteract the multiple comparisons problem of ten tests (i.e., Type I error) (Armstrong, 2014) and evaluated them against the corrected significance level of $p < 0.05$. We calculated Cohen's d to examine the effect size for the mean differences (Cohen, 1988). In the linear regression model, to indicate the importance of single explanatory variables on the formation of range anxiety, we used the conventional significance level $p < 0.05$. For evaluation of their practical significance, we standardize coefficients of the explanatory variables (β) and interpret them as effect size indices (Vittinghoff et al., 2005). As there are certain acknowledged difficulties in conventions for effect size measures in the context of multiple regression (Cohen, 1988), we will additionally evaluate omega-squared values ω^2 based on conventional thresholds (small < 0.06; medium > 0.06; large > 0.14) (Vaughan & Corballis, 1969). All analyses were conducted with the statistical software Stata 18 (StataCorp, 2023).

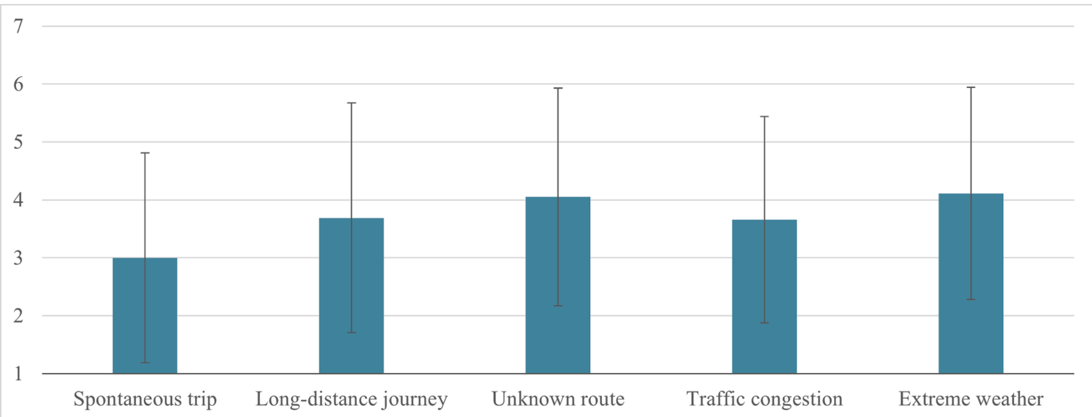

Fig. 2. Distribution of Means and Standard Deviations of Range Anxiety in Five Trip Settings.

4. Results

4.1. Descriptive statistics of range anxiety

According to the results in Fig. 2, range anxiety has the lowest mean on spontaneous trips ($M = 3.00$, $SD = 1.81$), followed by the anxiety level on long-distance journeys ($M = 3.69$, $SD = 1.98$), sudden traffic congestion ($M = 3.66$, $SD = 1.78$), unknown route ($M = 4.05$, $SD = 1.88$), and extreme weather situation ($M = 4.11$, $SD = 1.83$).

Based on the analysis results in Table 2, all mean differences are significant, except between traffic congestion and long-distance journeys, and between extreme weather and unknown routes. According to Cohen's d values, these two pairs do not reach a considerable effect size either. We identified medium differences ($d > 0.5$) in the means of range anxiety between spontaneous trips and unknown routes as well as between spontaneous trips and extreme weather situations. For the other six significant trip pairs, the effect size of the difference in means is rather weak ($d > 0.2$).

4.1.1. Dimensionality of range anxiety

We applied EFA to uncover the underlying structure of range anxiety measures in five trip settings. We yielded an *eigenvalue* of 3.57 for a one-factor solution and by considering Kaiser's criterion (Kaiser, 1958) of greater-than-one-rule, we found support for the one-dimensionality of the five range anxiety measures. This was also supported by visual inspections of the Scree plot and the Horn's parallel analysis. The analysis results in the following factor loadings for the five items: $\lambda = 0.90$ for unknown routes, $\lambda = 0.87$ for traffic congestion, $\lambda = 0.86$ for extreme weather $\lambda = 0.85$ for long-distance journeys, and $\lambda = 0.74$ for spontaneous trips.

4.2. Descriptive statistics of explanatory variables

Table 3 shows descriptive statistics for the main explanatory variables used in our hypothesis testing.

4.3. Multiple linear regression model

Table 4 presents the (un)standardized coefficients of explanatory variables in a multiple linear regression model that predicts overall range anxiety level. Based on the F-statistics, the linear model is highly significant and yielded an explained variance of 38.30 %.

4.3.1. EV driving experience (RQ_1)

In the first research question, we explore the association of EV driving experience with range anxiety. Based on the results of the linear regression model, we find support for a weak negative association between EV driving experience and range anxiety (H_1).

4.3.2. Charging-Related user experience (RQ_2)

In our second research question, we examine the relationship between charging-related user experience and range anxiety. According to the results, we reject hypothesis H_2 assuming that helpful charging guidance is related to a lower range anxiety. However, we find support for hypotheses H_3 and H_4, which indicate that the easier it is for an EV driver to charge with a battery level below 30 % or to charge less frequently than at present the lower the range anxiety. Both variables reach rather weak effect sizes, meaning a slight negative association with range anxiety. Also, we find support for hypothesis H_5 indicating that perceived ease of the charging process is negatively associated with range anxiety. For that, the effect size indicates a strong negative relationship between perceived ease of charging and range anxiety.

4.3.3. Psychological characteristics (RQ_3)

In our third research question, we address psychological characteristics and their relationship to range anxiety. Regarding technology openness, we reject hypothesis H_6 that the higher technology openness of an EV driver contributes to lower range anxiety. However, we find support for hypothesis H_7 that EV drivers with higher willingness to take risks perceive more range anxiety. Here the effect size can be considered as weak, hence there is only a minor negative relationship with range anxiety. Also, we find evidence for hypothesis H_8 that control beliefs are moderately negatively related to range anxiety.

Table 2
Cohen's d and Significance of Paired t-tests.

Trip setting	1	2	3	4
1. Spontaneous trip				
2. Long-distance journey	0.46*			
3. Unknown route	0.69*	0.30*		
4. Traffic congestion	0.41*	0.01	0.29*	
5. Extreme weather	0.66*	0.27*	0.06	0.41*

Note: * $p < 0.001$.

Table 3
Descriptive Statistics of Main Explanatory Variables.

Variable	Number of items	Min	Max	*M (SD)*
EV experience (in years)	1	0*	15	3.86 (2.77)
Perceived helpful charging guidance	1	1	7	5.31 (1.58)
Ease of charging at low SOC (< 30 %)	1	1	7	4.63 (1.94)
Ease of charging less frequently	1	1	7	4.39 (1.68)
Perceived ease of charging	2	1	7	5.81 (1.26)
Technology openness	4	1	7	4.00 (1.16)
Willingness to take risks	1	1	7	3.65 (1.33)
Control beliefs	2	1	7	5.50 (1.21)

Note: N = 1,005, EV = Electric Vehicle, SOC = State of Charge,
1 = Not at all, 7 = To a great extent, *Less than a year.

Table 4
Multiple Linear Regression Model for Range Anxiety.

Variable	*B*	*SE*	β	ω^2	Hypothesis
Age	0.01***	0.00	0.08	0.01	
Gender (1 = Female)	0.14***	0.06	0.07	0.01	
Village (1 = Yes)	−0.05	0.11	−0.01	0.00	
Town (1 = Yes)	−0.04	0.07	−0.02	0.00	
City (1 = Yes)	0.04	0.07	0.02	0.00	
EV experience	−0.02*	0.01	−0.06	0.00	H_1
Perceived helpful charging guidance	−0.02	0.02	−0.03	0.00	H_2
Ease of charging at low SOC	−0.06***	0.01	−0.10	0.01	H_3
Ease of charging less frequently	−0.05**	0.02	−0.08	0.01	H_4
Perceived ease of charging	−0.32***	0.02	−0.37	0.14	H_5
Technology openness	−0.05	0.03	−0.05	0.00	H_6
Willingness to take risks	0.06**	0.02	0.07	0.01	H_7
Control beliefs	−0.24***	0.03	−0.26	0.07	H_8

Note: N = 1,005, EV = Electric Vehicle, SOC = State of Charge.
*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$,
Adjusted $R^2 = 38.30$, F (13, 991) = 48.95 ($p < 0.001$).
Intercept: $\beta = 6.10$ (p < 0.001), *SE* = 0.25.

4.3.4. Socio-demographics (Control Variables)

In addition to the variables considered in the hypothesis testing, the demographics reveal some additional tendencies. Being an older or a female EV driver is slightly related to higher range anxiety. The settlement type of EV drivers does not have any significant relation to range anxiety.

5. Discussion

5.1. Research implications

One of the main contributions of our study is the exploration of a mix of factors describing drivers' demographics, their EV experience, perception of charging routine, and psychological characteristics. This enabled us to investigate range anxiety within a coherent and holistic framework. Moreover, we identified differences in the means of perceived range anxiety in five trip settings, which implies some context-based variation of range anxiety level. Thereby, more common and regular trip settings, such as spontaneous trips and traffic congestion are on average related to moderate range anxiety. Less frequent trip settings, such as long-distance journeys, unfamiliar routes, and extreme weather conditions, require more mental effort and preparation and are generally associated with higher average range anxiety.

Regarding demographics of EV drivers, we found that female EV drivers have more range anxiety, which can be explained by their overall need for convenience and preference for safety (Mckenna et al., 1998; Sovacool et al., 2019; Yuan et al., 2018). Higher age was also found to be related to more range anxiety, which can be partly due to the tendency of older EV drivers to utilize more range before next charging (Daina et al., 2015), thus having less flexibility. However, it could also be due to more regularity in their driving routine and their tendency to perceive daily stressors more actively compared to younger drivers (Stawski et al., 2008). Hence, in range-critical situations that imply more risk and discomfort, more support for female and older EV drivers is needed, for example, in the form of targeted charging suggestions and unsophisticated battery-related recommendations. We did not find support for the findings by Pevec et al. (2020) about the association between settlement size and range anxiety. This can be explained by a high share of home-based charging in Norway (Schulz & Rode, 2022), making charging less dependent on a location.

Our findings support previous studies that a longer EV driving experience is related to lower range anxiety, probably due to better-applied range coping skills and extended comfortable range (e.g., Philipsen et al., 2019; Rauh et al., 2020). However, as the overall effect size was marginal, it seems that more driving experience and knowledge of EVs could mean an advantage in some settings only. For example, this implies when the situation requires more technical understanding and strategic decision-making, such as unknown routes or very cold temperatures. In daily situations, more and less experienced EV drivers would probably both have sufficient coping skills and thus perceive range anxiety similarly.

Besides, our study did not yield support for the idea that helpful charging guidance in the form of in-vehicle or smartphone applications would contribute to less range anxiety which was suggested by several researchers (e.g., Eisel et al., 2016; Franke et al., 2016). This could be because we did not test a specific application or user design but evaluated how helpful and supportive drivers perceive the apps they currently use for charging. Our analysis indicates that perceived ease of charging is significantly associated with less range anxiety. It seems that the overall perception of the charging process and its coherence are important rather than only the aspect of providing helpful guidance and information about charging. When EV drivers feel comfortable about charging, they are likely well up with the overall charging process – from identifying the charging need to finding a charging opportunity and successfully carrying out charging. Probably, they are less stressed when facing a challenging or unexpected trip situation, which would require alteration of plans and the ability to cope with charging under different conditions. Hence, a smooth and comprehensible charging experience is one of the most important factors related to lower range anxiety of EV drivers. Interestingly, EV drivers evaluated, on average, both perceived ease of charging and helpful charging guidance as high. This means that conditions for anxiety-free charging experience are generally well-developed in Norway.

Furthermore, EV drivers' flexibility in terms of charging frequency and SOC at charging start is related to a lower range anxiety perception. The easiness of charging rarely is likely due to the availability of reliable local charging infrastructure (e.g., Neubauer & Wood, 2014). Besides, EV drivers who feel comfortable starting charging when the battery level is low, follow a necessity-based charging pattern, and their decisions are not triggered by their environment (e.g., Franke & Krems, 2013). The minor effect sizes of both variables could be because more flexible EV drivers are more relaxed about their range in daily situations. However, under more challenging circumstances, further individual aspects could be essential regarding the perception of range anxiety.

We could not find that technology openness is related to less range anxiety, which contrasts with previous findings by Philipsen et al. (2019). This indicates that EV drivers' perceived range anxiety may not depend on their technological interest controlling for other explanatory variables in our model. We found that willingness to take risks relates to a lower range anxiety, which supports another finding by Philipsen et al. (2019). Possibly, as researchers argued, low willingness to take risks is related to the avoidance of range-critical situations in the first place. Although the results showed a rather minor relation, drivers with risk aversion could be more willing to put effort into the preparation of their charging schedule by searching available charging stations, planning charging needs for the next trip, and determining alternative routes. In addition, we found that stronger control beliefs of EV drivers are associated with less range anxiety. Probably, those EV drivers who perceive themselves to be in control of the SOC and remaining range, plan enough buffer to encounter unexpected trip settings without additional anxiety and have available capabilities to monitor the whole charging process. While they encounter a challenging situation during a drive affecting their remaining range (e.g., low temperatures or longer trip duration), they would know how to cope with this by implementing battery-saving strategies.

5.2. Practical implications

The findings have several implications for improving our understanding of range anxiety. As we could identify moderate to small differences in the means of perceived range anxiety in five trip settings, in more challenging cases (e.g., extreme weather, unknown routes), it is relevant to provide EV drivers with context-specific support and information. For the automotive industry, our results imply that for lowering range anxiety in extreme weather conditions, particularly in regions with challenging climates, innovations in EV battery thermal management and providing weather-based battery-saving recommendations could help to maintain a comfortable range regardless of ambient temperature. In traffic congestion and on long-distance journeys, reliable and updated information about range-efficient route alternatives, traffic situations, and intermediate charging possibilities could help to make these trip settings more prepared. As a smooth charging process plays an important role regarding range anxiety, the industry could develop more seamless, user-friendly, and integrated charging solutions to simplify the charging experience. Particularly on long-distance journeys and trips with an unknown route, this could be done by improving the public charging network, enhancing compatibility across different charging stations and systems, and providing intuitive applications to streamline the charging planning process. Further, including capabilities for setting individual charging conditions and being able to monitor the whole process would keep the charging process comprehensive and maintain the feeling of control. This would be aligned with our findings that both the easiness of the charging process and sustaining drivers' control beliefs are associated with lower range anxiety.

Furthermore, our findings show that longer EV driving experience and younger age relate to lower range anxiety. Hence, spreading knowledge and awareness about range limitations and management could promote less range-anxious charging. Thereby, the inclusion of educational features and personalization of in-vehicle assistance could help EV drivers understand the capabilities and limitations of their vehicles. For example, by providing comprehensible and practical recommendations to older and less experienced EV drivers on when to charge and how to save their battery during the drive. Also, it could be useful to develop suggestions for those drivers with fixed charging schedules and safety preferences, regarding when and where they could integrate needed charging sessions based on their routine. With guidance on efficient driving techniques, battery management, and trip planning to support EV drivers, the practitioners (e.g., providers of driving training) and the automotive industry can empower EV drivers to make the most of their vehicles and have a positive user experience. Such educational resources can also help address common misconceptions about EV range and charging. Overall, context-based recommendations that are tailored to the needs of different EV driver segments are important for a seamless and anxiety-free charging experience.

5.3. Limitations and future research

Several limitations of our study should be considered as well as further research directions. Contrary to the experimental design which includes an intervention and control group, conducting statistical analysis based on (cross-sectional) survey data solely returns correlational results. Our non-experimental design could have introduced omitted variable bias that in turn could lead to endogeneity (e.g., Wilms et al., 2021). Therefore, it is not possible to draw causal inferences based on our study. However, a questionnaire study is an acknowledged method to gather information about novel aspects and provide data for testing hypotheses (Kelley et al., 2003), as has been done in previous studies (e.g., Franke & Krems, 2013; Philipsen et al., 2019). Another limitation related to our survey was that EV drivers could opt for "don't know" when evaluating their range anxiety in a particular situation. Hence, some EV drivers do not know how much anxiety they usually perceive in a given situation, either due to not having encountered it before or requiring more information to evaluate their range anxiety. Including the option "don't know" is a more ethical way to ask participants to answer questions where they may not be able to give an exact response (Fink, 2003). Furthermore, our study was conducted in Norway, where the EV adoption rate and the conditions for successful electric mobility are among the highest worldwide (Schulz & Rode, 2022). Therefore, the results cannot be generalized to every other country, with the potential exception of similar regions (e.g., other Nordic countries). However, it is reasonable to study the Norwegian market as this serves as an indicator for the future development of the overall EV market.

Future research could provide a deeper understanding of the different types of range anxiety trip settings as well as the underlying psychological, behavioral, and situation-specific factors. Particularly, conducting a field experiment with EV drivers to study how they perceive and tackle different trips or charging situations would help to understand the variety of aspects causing range anxiety to enable the development of more targeted and effective solutions. To move the focus from dealing with the consequences of range anxiety, such as expanding charging infrastructure or EV range, to healing its actual causes, it is important to provide support depending on individual characteristics and trip settings. Moreover, investigating measures and tools for clear and smooth charging would enable to maintain the feeling of control among drivers over their EV range as well as the whole charging process. Particularly, future charging technologies, such as vehicle-to-grid (V2G) (e.g., Mehdizadeh et al., 2023; 2024) will likely redefine the perception of range anxiety. As range-related comfort level could also be related to the vehicle usage pattern, future research could explore how the number of drivers or passengers of an EV relates to the perceived range anxiety. Besides, future research could explore the role of gamification and behavioral nudging techniques in mitigating range anxiety. Providing EV drivers with real-time feedback, personalized recommendations, and even game-like challenges could enable more engaging and empowering mobility solutions that help EV drivers overcome their range of concerns.

6. Conclusion

In the present study, we aimed to provide insights into range anxiety and factors associated with such anxiety. Based on the survey with over 1,000 diverse EV drivers in Norway, we explored how they perceive range anxiety in five different settings: spontaneous trips, long-distance journeys, unknown routes, sudden traffic congestion, and extreme weather conditions (e.g., cold temperatures). Moreover, we examined how demographics, EV driving, and charging-related user experience as well as psychological characteristics relate to the perception of range anxiety.

Our findings showed that range anxiety was on average lower on spontaneous trips and by sudden traffic congestion, followed by the anxiety level on long-distance journeys, unknown routes, and during extreme weather, respectively. Based on five variables measuring range anxiety in distinct trip settings, we aggregated them into one common factor describing range anxiety. We found that longer EV driving experience, easiness to start charging at low SOC (< 30 %) and to charge less frequently than at present, perceived ease of charging as well as willingness to take risks and stronger control beliefs are related to lower range anxiety. A higher age and female gender among EV drivers relate to a higher range anxiety. However, the perception of helpful guidance for charging and technology openness did not have any relation to range anxiety. Also, the settlement type where the EV drivers live does not relate to their range anxiety. The latter tendency should be investigated in further detail as it suggests that smaller settlements with a potentially less developed public charging network may not be subject to more range anxiety than larger ones. This questions the validity of labeling a comfortable EV use experience as a purely urban phenomenon.

As the adoption of EVs continues to grow, addressing range anxiety will be important not only for improving the charging experience but also for supporting sustainability and grid-stability goals. Our research findings suggest that providing situation- and user-based charging support and information, enabling more flexibility through more available charging opportunities and making the charging process smooth and comprehensive, are linked to anxiety-free charging behavior. Ensuring a feeling of control over own EV range and targeting particularly less-experienced, older, safety- and routine-based EV drivers, could further reduce range anxiety.

CRediT authorship contribution statement

Junianna Zatsarnaja: Writing – original draft, Formal analysis, Conceptualization. **Katharina Reiter:** Writing – review & editing, Conceptualization. **Milad Mehdizadeh:** Writing – review & editing, Conceptualization. **Alim Nayum:** Writing – review & editing, Conceptualization. **Trond Nordfjærn:** Writing – review & editing, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Questionnaire.

- How much stress does the range of your EV cause in the following situations? (Please rate every item on a scale from 1 to 7 where 1 means "not at all" and 7 means "to a great extent")
  a. For spontaneous/unplanned trips.
  b. For long-distance trips.
  c. For unknown routes.
  d. In case of unexpectedly high traffic volume/congestion.
  e. In case of extreme weather conditions (e.g., high or low temperatures).
- For me to only plug in my car at the State of Charge (SOC) lower than 30 % is very difficult (Please rate every item on a scale from 1 to 7 where 1 means "not at all" and scale 7 means "to a great extent").
- If I wanted to, it would be easy for me to charge my car less frequently (Please rate every item on a scale from 1 to 7 where 1 means "not at all" and scale 7 means "to a great extent").
- I receive enough helpful guidance in performing charging successfully (e.g., by my car or charging app). (Please rate every item on a scale from 1 to 7 where 1 means "not at all" and scale 7 means "to a great extent")
- Perceived ease of use (Please rate every item on a scale from 1 to 7 where 1 means "not at all" and scale 7 means "to a great extent")
  a. Interacting with the charging system at my main charging location is often frustrating.
  b. Charging my electric car requires a lot of mental effort.
- Risk (Please rate on a scale from 1 to 7 where 1 means "not at all" and 7 means "to a great extent")
  a. How much are you willing to take risks in your everyday life?
- Technology perception (Please rate every item on a scale from 1 to 7 where 1 means "not at all" and scale 7 means "to a great extent")
  a. Other people come to me for advice on new technologies.
  b. In general, I am among the first in my circle of friends to acquire new technology when it appears.
  c. When I acquire a new technological device, I am soon familiar with its functions.
  d. I rather stick to conventional technology which already proved to be working.
- Control beliefs (Please rate every item on a scale from 1 to 7 where 1 means "not at all" and scale 7 means "to a great extent")
  a. Having enough remaining range in my car is entirely up to me.
  b. I feel in complete control over the State of Charge (SOC) of my car.

- What is your age? (Please choose one option)

a. 18 – 24 years
b. 25 – 34 years
c. 35 – 44 years
d. 45 – 54 years
e. 55 – 64 years
f. Above 64 years

- What is your gender? (Please choose one option)

a. Male
b. Female

- What is your working status? (Please choose one option)

a. Student
b. Employed
c. Unemployed
d. Retired
e. Disabled/Rehabilitation
f. Homewife/husband

- What is your highest level of education? (Please choose one option)
  a. Primary or secondary school.
  b. High school.
  c. University/college.

d. Other.

- How would you describe the place where you live? (Please choose one option)
  a. Village (population less than 1,000).
  b. Town (population between 1,000 and 100,000).
  d. City (population between 100,000 and 300,000).
  e. Large city (population between 300,000 and 1 million).

- Do you own or lease the EV you usually drive? (Please choose one option)
  a. I am the owner of the EV.
  b. My family member is the owner of the EV.
  c. I am the leaseholder of the EV.
  d. My family member is the leaseholder of the EV.
  e. I drive a company car.
  f. Other.

- How many years have you been driving an EV in general (in years)? [open answer field]

Data availability

Data will be made available on request.

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