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Does this range suit me? Range satisfaction of battery electric vehicle users

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ABSTRACT

User satisfaction is a vital design criterion for sustainable systems. The present research aimed to understand factors relating to individually perceived range satisfaction of battery electric vehicle (BEV) users. Data from a large-scale BEV field trial ($N = 72$) were analyzed. Apart from an initial drop in range satisfaction, increasing practical experience was related to increased range satisfaction. Classical indicators of users' mobility profiles (daily travel distances) were only weakly related to lower range satisfaction (not significant), after controlling for practical experience and preferred coverage of mobility needs. The regularity/predictability of users' mobility patterns, the percentage of journeys not coverable because of range issues, and users' individual comfortable range accounted for variance in range satisfaction. Finally, range satisfaction was related to key indicators of general BEV acceptance (e.g., purchase intentions). These results underline the complex dynamics involved in individual range satisfaction, as well as its central role for BEV acceptance.

1. Introduction

Battery electric vehicles (BEVs) can contribute to sustainable road transport (e.g., Williams et al., 2012). Limited range however represents a significant drawback of BEVs compared to standard combustion vehicles (CVs). This disadvantage can deter potential customers (Dimitropoulos et al., 2013; Egbue and Long, 2012) or lead them to purchase BEVs with high range setups that are neither especially cost-efficient, nor the most sustainable solution due to the ecological footprint of particularly large batteries (McManus, 2012; Yuan et al., 2015; Neubauer et al., 2012). Practical experience with BEVs however can change an individual's perception and experience of limited range (e.g., Bunce et al., 2014; Franke and Krems, 2013c; Labeye et al., 2016). Stated differently, it can be difficult for potential BEV customers lacking practical BEV experience to estimate the range they would actually perceive as satisfactory upon becoming familiar with a BEV, i.e., the range satisfaction in daily usage. Research is therefore required to determine which factors are related to individually perceived range satisfaction in daily BEV usage (i.e., which factors need to be considered to estimate subjectively suitable range).

Does this range suit me? This is a key question for any potential BEV customer. A common approach for identifying suitable range is to infer the fit of certain range setups based on analyses of mobility patterns (e.g., Pearre et al., 2011; Krumm, 2012; Tamor and Milačić, 2015; Weiss et al., 2016; Greaves et al., 2014). A basic notion in this important branch of research is that key indicators of mobility needs are related to BEV acceptance. Typical mobility profile indicators, like average or maximum daily travel distance, should therefore account for a considerable share of variance in range satisfaction. Nevertheless, these indicators may fail to cover all relevant mobility profile facets. That is, aspects such as the regularity/predictability of daily mobility needs (i.e., to what extent do trips and travel distances follow regular patterns and/or are predictable well in advance) or the distances that users really have to cover between convenient charging opportunities.

Moreover, research indicates that changing from CV to BEV usage involves adaptation processes that may limit the predictive power of CV mobility for range satisfaction. BEV drivers typically adapt to range over the first weeks of usage (e.g., Labeye, et al., 2016; Rolim et al, 2012; Bunce et al., 2014), and view BEVs more positively after gaining experience (e.g., Bühler et al., 2014; Carroll and Walsh, 2010; Franke and Krems, 2013c; Schneider et al., 2014). In addition, more practical experience is typically related to better

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user experience and interaction with range (e.g., Franke et al, 2015b; Pichelmann et al., 2013; Wikström et al., 2014).

Further, there are typically inter-individual differences regarding which *psychological range* a BEV offers for a driver (e.g., Franke and Krems, 2013a; for similar notions see Burgess et al., 2013). For example, based on different factors (e.g., ecodriving propensity, stress resistance) drivers will obtain a different *available* (i.e., displayed) range under everyday conditions (i.e., performant range; Franke and Krems, 2013a) and a different *comfortable* range (i.e., the actual usable range of the BEV; Franke, et al, 2015a). As these range levels influence the actual usable range, they should be relevant for range satisfaction (for first results see Franke and Krems, 2013a). That is, if we understand range satisfaction as the perceived fit of mobility needs to mobility resources, then inter-individual variability of actual range resources should be a relevant factor.

Finally, range is merely one BEV attribute (Rezvani et al., 2015; Egbue and Long, 2012). General BEV acceptance will thus be dependent on much more than just range satisfaction (e.g., environmental concerns, other car attributes beyond range). A final relevant topic is therefore to quantify the relevance of range satisfaction to general BEV acceptance (e.g., purchase intentions).

2. Present research

The objective of the present research was to understand factors contributing to individually perceived range satisfaction in daily BEV usage (i.e., which factors are relevant to the actual range satisfaction that car drivers experience once they have driven a BEV in daily usage), as well as provide insight into the role of range satisfaction for general BEV acceptance. Specifically, this study has addressed the following five research questions (hypotheses are summarized in Table 1).

(Q1) How is practical experience related to range satisfaction (i.e., test of adaptation effects)? Here we examine the longitudinal development of range satisfaction, as well as the effect of general accumulated practical experience and specific experience with range from actively exploring low-range situations (parallel to analyses of practical experience effects on range stress in Franke et al., 2016).

(Q2) How are mobility profile indicators related to range satisfaction? Not only does this question investigate the standard indicators of average and maximum daily travel distances (Pearre et al., 2011; Chlond et al., 2014), but it also addresses the typical distances that have to be covered between charging opportunities, and the regularity/predictability of a user's mobility profile.

(Q3) How is the actual and preferred coverage of mobility needs related to range satisfaction? This question essentially examines to what extent the coverage of mobility needs can account for range satisfaction.

(Q4) How are individual differences in psychological range related to range satisfaction? This concentrates on the two core range levels relevant to the daily interaction with range: performant range (Franke and Krems, 2013a) and comfortable range (Franke et al., 2015a).

(Q5) How important is range satisfaction for general BEV acceptance? This final question focuses on the key indicators general satisfaction and perceived usefulness (van der Laan et al., 1997), intention to recommend (Reichheld, 2003), purchase intentions (Bühler et al., 2014; Plötz et al., 2014) and range preferences (Franke and Krems, 2013c).

3. Method

3.1. Field study setup

The present research constitutes part of a large-scale BEV field trial in the region surrounding Leipzig, Germany. The field trial was designed to address different topic clusters related to user-range interaction; one of these being range satisfaction. Within the field trial, there were four main time points of data collection: before vehicle handover (T0), after the first week of BEV usage (T0+1), after six weeks (T1), and at vehicle return after 12 weeks (T2). At each point of the data collection, users completed interviews and questionnaires. A person-based main user data collection approach was applied, i.e., only data derived from the main user of the BEV was analyzed. The BEV utilized was the BMW ActiveE with a maximum available driving range of 130–160 km in real terms, depending on driving style (Ramsbrock et al., 2013). Users had charging opportunities at home and/or at work depending on their mobility patterns. Fifteen BEVs were available for the study. Five subsequent data collection phases allowed a sample of 75 drivers. For further methodological details, see Franke et al. (2014a).

3.2. Participants

To enable the recruitment of a maximum diverse sample, information on the project was broadly distributed via different media channels, such as radio, local television, newspaper, online media, and events. Participants applied via an online screener questionnaire (673 applicants). Requirements for participation included (1) the willingness to pay the monthly full service leasing rate of 450 € (reduced to 370 € when the BMW i3 entered the market), (2) a charging opportunity or the possibility to install a charging station, and (3) a mobility profile that could be expected to result in a need to concern oneself with range (≥90 km daily driving distance with the BEV). The $N = 72$ users who completed

Table 1
Hypotheses tested in the present study.

Factor tested	Hypothesis	Specification of hypothesis
Practical experience	H1a	Range satisfaction increases with practical experience.
	H1b	Higher accumulated practice with the BEV in terms of general total distance driven and specific exploration of low-range situations is related to higher range satisfaction.
Mobility profile	H2a	Shorter daily travel distances and shorter driving distances between charging opportunities are related to higher range satisfaction.
	H2b	A more regular/predictable mobility profile is related to higher range satisfaction.
Coverage of mobility needs	H3	A higher actual coverage of mobility needs and a lower preferred coverage of mobility needs are related to higher range satisfaction.
Psychological range levels	H4	A higher psychological range in terms of comfortable range and performant range is related to higher range satisfaction.
General BEV acceptance	H5	A higher range satisfaction is related to key indicators of a higher general BEV acceptance.