Does range matter? Exploring perceptions of electric vehicles with and without a range extender among potential early adopters in Germany

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Abstract

High CO₂ emissions, air pollution and fossil fuel consumption require an energy transition in the transportation sector. Battery electric vehicles (BEVs) represent one way to achieve this. However, limited range is one of the major barriers to their widespread adoption. A BEV with a range extender (i.e., extended range electric vehicle, EREV) could be one sustainable solution to this problem. The present study examines the acceptance of EREVs relative to BEVs among a sample of early adopters. Specifically, we investigate whether indicators of mobility needs and acceptability of range extender usage predict individual differences in acceptance of EREVs versus BEVs. In total, 112 potential early adopters of EVs in Germany with previous limited-range mobility experience were surveyed. On average, both vehicle concepts were highly appreciated; however, BEVs were appreciated slightly more. EREVs with higher total range received higher valuation ratings, but only if there was no significant reduction in battery range. Yet, there were also substantial individual differences in acceptance of EREVs versus BEVs. These differences were related to certain indicators of mobility needs and the acceptability of range extender usage.

Key Words: Electric vehicle; Range extender; Acceptance; Mobility needs

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1 Introduction

About 22% of the CO₂ emissions in Europe are caused by transportation systems (European Commission, 2013). Furthermore, other harmful environmental impacts like air pollution intensify in specific areas, for example due to increasing urbanization (Araújo, 2014). This leads to an increased need for real change in the transportation sector to protect the environment. One solution to this is to increase the electrification of transportation. In particular, (hybrid) electric vehicles with a plug-in function have great potential for reducing greenhouse gas emission (e.g., Ida, Murakami, & Tanaka, 2014). However, in order to ensure a successful introduction of such sustainable transportation systems into the market, a comprehensive perspective that does not only consider technological aspects, but also social science and psychological issues (e.g., consumer behavior), is necessary (see e.g., Sovacool, 2014).

In recent years, a lot of attention has been given to electric vehicles (EVs), especially battery electric vehicles (BEVs). Many advantages are associated with BEVs by potential customers, such as environmental friendliness (i.e., the “green image”) and the specific driving experience (i.e., the pleasure of driving a vehicle with pure electric drive; e.g., Bühler, Cocron, Neumann, Franke, & Krems, 2014). However, there are also several consumer concerns, such as long charging time, high purchase costs and limited range (e.g., Bühler et al., 2014; Ziegler, 2012). In fact, limited range is regarded as one of the main disadvantages of BEVs (e.g., Bühler et al., 2014; Skippon & Garwood, 2011).

A sustainable solution might be the implementation of BEVs with a range extender (extended range electric vehicles, EREVs). An EREV has a relatively small battery to cover usual trips and a considerably downsized combustion engine that can extend the range to cover longer trips, when needed. Hence, it offers the opportunity to overcome the psychological range barrier in a sustainable way (i.e., without the need of a large battery and without the need of a higher share of combustion-based propulsion that can be expected with
Does Range Matter?

Because of the extended range feature, one could imagine that many customers would prefer an EREV instead of a BEV. However, experience with limited-range mobility can change range preferences (Franke & Krems, 2013a). Hence, the question is how EREVs and BEVs are accepted in more mature markets, where more people will likely have more experience with limited range.

While there is a growing body of literature on BEV acceptance (e.g., Jensen, Cherchi, & Ortúzar, 2014; Bühler et al., 2014; Schuitema, Anable, Skippon, & Kinnear, 2013), there is very little research on the perception and acceptance of EREVs. The present study investigates consumer acceptance of EREVs relative to BEVs among a sample of potential early adopters of EVs in Germany who have previous experience with limited-range mobility. Moreover, the study examines whether individual differences in acceptance of EREVs versus BEVs are related to mobility needs and the acceptability of range extender (RE) usage.

We focused on participants who already had first experience with limited range because research has shown that such experience is necessary for individuals to be able to form estimates that predict customers’ acceptance in more mature markets (e.g., Franke & Krems, 2013a; Kurani, Turrentine, & Sperling, 1994). Because of this, our sample consists of potential early adopters of EVs. Early adopters are also an interesting group because they often function as opinion leaders, as they have a high degree of influence on other potential adopters (Rogers, 2002). They are the individuals who potentially advertise for or against a product through word of mouth and/or customer reviews, which can have a great deal of influence on the general perception of products in modern markets (Chevalier & Mayzlin, 2006).

Moreover, although our study focused on a German sample it may generalize to other populations because EV market development (i.e., diffusion of EVs) follows similar processes and is currently at a similar stage in different countries (see section 6.3).
2 Background

2.1 Values and schemata regarding automobility

Part of the reason why BEVs have not yet achieved widespread success in the market could be that consumers are often reserved regarding new technologies – they rely on traditions and familiarity (Sovacool & Hirsh, 2009). For example, in the beginnings of the 20th century, BEVs had a higher market share than gasoline vehicles because they required the lowest level of adaptation (i.e., they fitted best with traditions and familiar mobility patterns). BEVs were most similar to common horse carriages in terms of speed, power, range, sound and durability. Hence, a BEV matched the values that customers had learned were important for individual mobility.

Yet, following the cultural adaptation to the automobile, the increase of gasoline powered vehicles led to the formation of new mobility values, such as higher range and speed. At this time, when new values emerged, BEVs were starting to be viewed as “horsey” and feminine (Sovacool, 2009).

Today, the BEV is beginning to attract attention again. However, after having adapted to high range mobility over the past 100 years, adoption of a BEV requires a fundamental adaptation because it does not fit with familiar characteristics of automobility. From this perspective, an EREV might be a vehicle concept that provides a better subjective fit for many car drivers because it matches current automobility values (i.e., familiar characteristics of mobility) better than a BEV.

Another concept that can be added to this perspective is the work of Mandler (1982), who theorized that products that are highly incongruent with existing schemata (e.g., in our context the schema of automobility) are evaluated negatively because they cannot easily be integrated into existing schemata. Schema in this context means a mental structure that
organizes past experiences (i.e., what are the characteristics of automobility that one has primarily experienced so far).

Because a BEV and the associated mobility features do not fit well with current automobility schemata, a BEV can be seen as a highly incongruent product. In contrast, an EREV is more congruent because it includes more common features (e.g., the combustion-based RE, higher range).

In the near future, the schemata of automobility will probably change to some degree, as markets gain more potential customers who already have experience with limited-range mobility. For example, individuals may develop more accurate representations of their real mobility needs (e.g., Franke & Krems, 2013a) and might not view automobility as being synonymous with high range. Hence, the acceptance of different alternative vehicle concepts like EREVs and BEVs may also change in such future markets.

Additionally, it can be expected that there are potential individual differences in the perceived automobility value incongruity of an EREV versus a BEV, especially when individuals have a more precise understanding of their mobility needs (i.e., because of their experience with limited range). Hence, it can be expected that mobility needs (i.e., typical mobility patterns) predict individual variations in acceptance of EREVs versus BEVs. In the literature, different indicators of mobility needs are used when discussing sufficient EV range – for example, the average daily driving distance (e.g., Bunzeck, Feenstra, & Paukovic, 2011), the longest daily driving distance per week or per year (e.g., Chlond, Kagerbauer, Vortisch, & Wirges, 2012; Greene, 1985) or the share of daily mobility needs in one year that can be met by a typical EV range (e.g., Pearre, Kempton, Guensler, & Elango, 2011). The question is which parameter of mobility needs predicts individual acceptance of EREVs versus BEVs.
2.2 The importance of driving purely electric

The fit to existing schemata of automobility is not the only important factor influencing acceptance. Research has shown that the green image of alternative fuel vehicles is another factor that influences car buyers’ intentions to purchase such a vehicle (e.g., Kang & Park, 2011; Schuitema et al., 2013). Hence, the combustion engine of an EREV could be a potential barrier for their widespread adoption because it reduces the perceived green image of an EV (i.e., no “pure” electric driving).

Yet, there will also be individual differences in the preference for driving purely electric. Some potential customers may prefer to use a RE as seldom as possible to retain the green image; whereas others may not hesitate to utilize the combustion engine. Hence, the question is if the acceptability of RE usage (i.e., the individual importance of driving purely electric) predicts individual differences in acceptance of EREVs versus BEVs.

2.3 The assessment of acceptance

In order to investigate acceptance of the different vehicle concepts, the methodology for assessing acceptance must be specified. At present, there is no standard method for assessing acceptance of alternative fuel vehicles. In the literature, often attitudes or perception (e.g., Bühler et al., 2014; Gärling & Johansson, 1999; Skippon & Garwood, 2011), intention to purchase, recommend or adopt (e.g., Gärling & Johansson, 1999; Bühler et al., 2014, Jabeen, Olaru, Smith, Braunl, & Speidel, 2012, Schuitema et al., 2013) or willingness to pay (e.g., Bühler et al., 2014) have been used to assess acceptance.

For the present study, we limited our assessment of acceptance to appreciation (in terms of a general perception) and valuation (in terms of an actual willingness to pay) because of the need to maintain an economic study design.

3 Research questions and hypotheses

The following research questions were addressed in the present study:
(Q1) Is the EREV concept an alternative to the BEV concept from the viewpoint of individuals who already have experience with limited range? Specifically:
  o (Q1.1) How are EREVs generally appreciated relative to BEVs?
  o (Q1.2) How are EREVs valued relative to BEVs?

(Q2) Do the theorized factors predict individual differences in acceptance of EREVs versus BEVs? Specifically:
  o (Q2.1) Do mobility needs predict individual differences in acceptance of EREVs versus BEVs?
  o (Q2.2) Does the acceptability of RE usage predict individual differences in the acceptance of EREVs versus BEVs?

Regarding Q2.1, we hypothesize that potential early adopters of EVs who indicate higher appreciation and valuation of EREVs than BEVs have …
  - (H1) … higher average daily driving distances.
  - (H2) … higher maximum daily driving distances (e.g., in a typical week).
  - (H3) … a higher percentage of days that they estimate that their mobility needs will exceed the typical BEV range.

Regarding Q2.2, we expect that potential early adopters of EVs who indicate higher appreciation and valuation of EREVs than BEVs …
  - (H4) … would accept the use of the RE on more days.

4 Method

The present study was conducted within the framework of the project EVREST (Electric Vehicle with Range Extender as a Sustainable Technology), which was funded by the German Federal Ministry of Economics and Technology, the French Environment and Energy Management Agency and the Austrian Federal Ministry for Transport, Innovation and Technology within the European funding scheme Electromobility+. One goal of the project
was to examine the user perspective on EREV technologies. Therefore, a questionnaire study was designed.

4.1 Participants

For the present research, we investigated potential early adopters of EVs with previous limited-range vehicle experience. Because EVs require fundamentally different mobility routines, studies without experienced users have been argued to have only limited applicability to more mature markets (e.g., Kurani, Turrentine, & Sperling, 1994). For inexperienced users, it is difficult to mentally simulate the impact of certain EV characteristics on their daily life (e.g., the interaction with limited range). We focused on potential early adopters of EVs with substantial BEV experience. This was determined based on the total driven km with a BEV. Participants were required to have a minimum of 100 km of BEV driving experience.

At present, it is difficult to find such experienced BEV drivers in European markets. However, we had access to the contact data of experienced BEV drivers from a German BEV field study (applicants and participants of the field study “BMW ActiveE Leipzig – long-distance commuters”; see Franke et al., 2014) and were able to recruit additional potential early adopters of EVs with BEV experience via a newsletter for people interested in electric mobility (electrive.net newsletter, more than 6000 daily recipients). Regarding the field study participants, it is important to note that the project was a publicly funded, meaning that recruitment was focused on the general population of early adopters of EVs. The subsidized full-service leasing rate of 450 € (leasing rate reduced during the field trial to 370€) was similar to that of other typical BEVs (i.e., the sample can be assumed to represent typical potential early adopters). In addition, it is expected that participants recruited via the newsletter are highly interested in EVs, and therefore, may be potential early adopters of EVs.
Overall, 74 of the participants were applicants or participants in the “BMW Active E – long distance commuters” field study and 38 of the participants were recruited via the newsletter. Except for gender, there were no significant differences between the two sub-samples (see Table 1). Hence, we analyzed the whole sample together. The final sample consisted of 112 participants, 10 females and 102 males, and was on average $M = 43$ ($SD = 10.58$) years old. About 64% of the participants had a university degree and about 34% of the participants a total household income of 3000€ - 4499€. These demographic characteristics are typical for samples of early adopters of EVs (e.g., Wietschel et al., 2012, Vilimek & Keinath, 2014). On average, BEV driving experience was about $M = 5029$ km ($SD = 8548, min = 100, P25 = 800, P75 = 6369, max = 70000$).

### Table 1

Descriptive statistics of the sub-Samples and the combined sample.

<table>
<thead>
<tr>
<th></th>
<th>Applicants/ participants of the field study</th>
<th>Participants recruited via newsletter</th>
<th>Whole sample</th>
<th>Significance test between the two sub-samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>74</td>
<td>38</td>
<td>112</td>
<td></td>
</tr>
<tr>
<td><strong>Gender</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>female</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>$\chi^2 (1) = 5.64, p = .030$</td>
</tr>
<tr>
<td>male</td>
<td>64</td>
<td>38</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>$M = 43.38$ ($SD = 8.65$)</td>
<td>$M = 43.03$ ($SD = 13.71$)</td>
<td>$M = 43.26$ ($SD = 10.58$)</td>
<td>$t(52.54) = 0.14, p = .886$</td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>still in education</td>
<td>0%</td>
<td>3%</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>vocational education</td>
<td>19%</td>
<td>8%</td>
<td>15%</td>
<td>$\chi^2 (3) = 4.41, p = .191$</td>
</tr>
<tr>
<td>master/ professional school</td>
<td>20%</td>
<td>18%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>university</td>
<td>61%</td>
<td>71%</td>
<td>64%</td>
<td></td>
</tr>
<tr>
<td><strong>Household’s total income</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 1499€</td>
<td>3%</td>
<td>5%</td>
<td>4%</td>
<td></td>
</tr>
<tr>
<td>1500€ - 2999€</td>
<td>19%</td>
<td>26%</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>3000€ - 4499€</td>
<td>36%</td>
<td>29%</td>
<td>34%</td>
<td>$\chi^2 (5) = 3.77, p = .603$</td>
</tr>
<tr>
<td>4500€ - 5999€</td>
<td>18%</td>
<td>21%</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>&gt; 6000€</td>
<td>18%</td>
<td>8%</td>
<td>14%</td>
<td></td>
</tr>
<tr>
<td>No answer</td>
<td>7%</td>
<td>10%</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td><strong>BEV driving experience</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$M = 4686$ ($SD = 6041$)</td>
<td>$M = 5696$ ($SD = 12103$)</td>
<td>$M = 5029$ ($SD = 8548$)</td>
<td>$U = 1238.50, z = -1.03, p = .303$</td>
<td></td>
</tr>
</tbody>
</table>

*Note. Significance tests were two-tailed. $A = $ one cell has an expected cell value < 5. $B = $ two cells have expected cell values < 5. $C = $ three cells have expected cell values < 5. However, several studies report robust test results with little cell proportions (see e.g., Delucci, 1983; Good, Gover, & Mitchell, 1970). For BEV driving experience: $N = 33$ applicants/ participants of the field study*
4.2 Definition of the EREV concept

In the literature, there is no common established definition of EREVs (e.g., see California Code of Regulations, 2014; Tate, Harpster, & Savagian, 2008). For the current research, we define EREVs as follows: The EREV is technically based on a BEV and has an additional electric power generating unit, an internal combustion engine fueled by gasoline that powers an electric generator, which is capable of supplying electricity to the onboard network, and therefore, extends range without the need to increase battery size. The difference between a plug-in hybrid EV (e.g., Chevrolet Volt, Mitsubishi Plug-In Hybrid Outlander) and the EREV is that the combustion engine is considerably downsized in EREVs compared to plug-in hybrid EVs. Therefore, the combustion engine (RE) is only designed for the more infrequent longer trips.

At the beginning of the questionnaire, the EREV concept was defined using three modules. Module (1) provided general information about the EREV concept. It was highlighted that an EREV has an additional combustion engine, which can recharge the battery and extend the range. For that reason, the RE is intended to be utilized only for the rare occasions in which the driver requires substantially more range than is typical. In module (2), the essential differences between an EREV and (a) a hybrid EV as well as (b) a BEV were described. In this part, the degraded mode as a specific feature of the EREV was introduced (i.e., a mode with non-restricted range). In this mode, the vehicle power is reduced (e.g., a max speed of 90 km/h), as the RE is usually a downsized power source. Furthermore, it was emphasized in this module that the characteristic driving experience of a BEV is mostly retained. Module (3) discussed implications of the use of an EREV in everyday life using four different possible scenarios. Participants received the following descriptions: (a) You can drive your daily trips within the battery range completely without the RE. Hence, you drive purely electric. (b) If the trip becomes longer unexpectedly (e.g., due to a detour), an activation of the RE will extend the driving range. (c) If you want to take a long trip, you
will be able to activate the RE at the beginning of the trip, and consequently, have the maximum available range (i.e., the full power range). And (d) if the battery is completely discharged, the car will not stop. Instead, you will be able to reach at least the next charging station in degraded mode.

4.3 Vehicle configurations

In the present study, we examined three EREV configurations which were defined by the EVREST consortium:

- EREV1: 50 km battery range; 150 km full power range, 90 km/h in degraded mode
- EREV2: 50 km battery range; 300 km full power range, 90 km/h in degraded mode
- EREV3: 100 km battery range; 300 km full power range, 90 km/h in degraded mode

As a comparison benchmark, we chose a BEV with a battery range of 150 km (i.e., a typical range capability at present). Users were informed that all range values indicated real-life values (i.e., real available range under everyday conditions, performant range, see Franke & Krems, 2013b) and not technical range (i.e., based on driving cycle results).

4.4 Questionnaire scales

4.4.1 Appreciation of EREVs versus BEVs

To assess appreciation, two single-item indicators were used: (1) “I appreciate BEVs” and (2) “I appreciate EREVs”. Participants rated these statements on a 6-point Likert scale from 1 (= completely disagree) to 6 (= completely agree).

4.4.2 Valuation of EREVs versus BEVs

Valuation was assessed using four willingness-to-pay items (one for each vehicle configuration). In the literature, two different approaches to assess willingness to pay are noted – direct and indirect methods (see e.g., Miller, Hofstetter, Krohmer, & Zhang, 2011). Because of the need to design an economic questionnaire, we used the direct approach (i.e.,
open-ended question format) for this study. Moreover, Miller et al. (2011) found that an open-ended question format can be as valid as a choice-based conjoint measure.

Participants were instructed to imagine that they are planning to buy a vehicle like the BMW i3 (4 seats, 200 l luggage compartment, 170 PS; in order to standardize all vehicle characteristics except for range) and do not have to worry about battery life. Afterwards, they were instructed to indicate a purchase price which they assessed to be high, but just acceptable for each of the four vehicle configurations.

4.4.3 Mobility needs

For the present analysis, five open-ended items were included in the questionnaire to assess relevant indicators of mobility needs. The participants were asked to estimate their average daily driving distance on a workday (labeled “$M_{\text{Workday}}$”), their average daily driving distance on a weekend day (labeled “$M_{\text{Weekendday}}$”), their maximum daily driving distance on a typical weekday (labeled “$\text{Max}_{\text{Dayin typical Week}}$”) and the longest distance they drove in one day over the last month (labeled “$\text{Max}_{\text{Dayin last Month}}$”). In addition, we calculated the average daily driving distance of a typical weekday (labeled “$M_{\text{whole Weekday}}$”). $M_{\text{whole Weekday}}$ is the sum of $M_{\text{Workday}}$ multiplied by five and $M_{\text{Weekendday}}$ multiplied by two, divided by seven (i.e., a weighted average of the two variables). To assess the percentage of days in which mobility needs exceed typical BEV range, the participants estimated the number of days each month that their mobility needs exceed 150 km, and consequently, other modes of transportation are needed (labeled “$\text{Range}_{150 \text{not sufficient}}$”).

We are aware of the fact that these key mobility figures are difficult for participants to estimate. However, these mobility questions were developed and pilot tested across several studies that we conducted over the last few years. For example, it was previously found with a similar sample of EV users that the estimations of such mobility indicators where highly similar to the data assessed by travel diaries (Krems et al., 2011). In addition, we utilized
clear instructions and frames of reference to reduce the risk of misunderstanding (e.g., “For the following questions please think of a typical week!”). Furthermore, we conducted plausibility tests (e.g., Max\textsubscript{DayintypicalWeek} must not be smaller than M\textsubscript{Workday} or M\textsubscript{Weekendday}) to screen for participants who misunderstood certain mobility items due to difficulties with comprehension or carelessness (see section 5.2).

### 4.4.4 Acceptability of RE usage

Participants were asked about the acceptable number of days of RE usage per month. The item text was “On how many days per month would you accept needing to use the RE because of insufficient battery range?” (labeled “RE\textsubscript{accepted}”).

## 5 Results

To answer our research questions, we analyzed our data using descriptive statistics as well as Mann-Whitney-U-tests and Wilcoxon-Mann-Whitney-tests with an alpha of .05. Nonparametric tests were used because our data were not normally distributed. Additionally, we calculated Cohen’s $d$ as a measure of effect size.

### 5.1 Acceptance of EREVs Versus BEVs (Q1)

#### 5.1.1 Appreciation of EREVs Versus BEVs

With respect to Q1.1, “How are EREVs generally appreciated relative to BEVs”, data showed that both vehicle types were generally judged positively (see Table 2). In fact, the majority of participants agreed with the statements (see agreement % column). However, it can be seen that, on average, BEVs were viewed more positively than EREVs ($z = -3.34$, $p = .001$, $d = 0.32$, two-tailed test). Interestingly, more than half of the participants (54%) gave the BEV the highest possible rating (i.e., completely agreed), whereas only 37% of the participants rated EREVs this way. There was no relationship between appreciation of BEVs and EREVs (Spearman’s rho = -.076, $p = .426$). Of course, all findings reported in the present
paper regarding absolute levels of acceptance must be interpreted in light of the special characteristics of our sample.

**Table 2**

Descriptive statistics for appreciation.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>P25</th>
<th>P75</th>
<th>agreement %</th>
<th>completely agree %</th>
</tr>
</thead>
<tbody>
<tr>
<td>I appreciate BEVs</td>
<td>111</td>
<td>5.21</td>
<td>1.15</td>
<td>5</td>
<td>6</td>
<td>89 %</td>
<td>54 %</td>
</tr>
<tr>
<td>I appreciate EREVs</td>
<td>111</td>
<td>4.57</td>
<td>1.48</td>
<td>3</td>
<td>6</td>
<td>75 %</td>
<td>37 %</td>
</tr>
</tbody>
</table>

*Notes.* For agreement % value, we dichotomized the 6-point Likert scale (i.e., calculated percentage of users who endorsed scale values from 4 (“slightly agree”) to 6 (“completely agree’’)). One participant did not answer the items. Hence, \( N = 111 \).

Apart from this general trend, there was considerable variance in participants’ answers. Although there were several participants who appreciated both EREV\s and BEVs equally (34%), the majority of participants exhibited a clear preference for one of the two vehicle concepts in terms of appreciation (66%). However, because the appreciation variables were not normally distributed, we had to create two groups in order to investigate individual differences in appreciation of EREV\s versus BEVs. These groups were created by taking the difference between the two appreciation ratings. The frequencies showed that 49 participants appreciated BEVs more than EREV\s and 24 participants appreciated EREV\s more than BEVs. In the remaining analyses, we call these two groups: (1) appreciation pro BEV concept and (2) appreciation pro EREV concept.

### 5.1.2 Valuation of EREV\s versus BEVs

With respect to Q1.2, “How are EREV\s *valued* relative to BEVs?”, data showed that on average participants would pay the most for the EREV3, followed by the prototypic BEV, the EREV2 and finally the EREV1 (see Table 3). The results indicate that participants would pay, on average, 2814€ more for an increase of full power range from 150 km to 300 km (when battery range is kept constantly; i.e., comparison of EREV1 and EREV2) and 4320€ more for
an increase of battery range from 50 km to 100 km (when full power range is kept constantly; i.e., comparison of EREV2 and EREV3). Hence, an increase of battery range seems to be more important for potential customers than an increase of full power range.

Based on a technical cost calculation by partners in the EVREST consortium a realistic purchase price would be about 30,000€ for the BEV, 22,000€ for the EREV1, 24,000€ for the EREV2, and 28,000€ for the EREV3. It is obvious that only the price for the BEV is substantially higher than participants’ valuation. The willingness to pay for the EREV configurations was quite similar to the estimated prices by the consortium.

**Table 3**

Descriptive statistics for valuation in Euro.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>M</th>
<th>Mdn</th>
<th>SD</th>
<th>P25</th>
<th>P75</th>
<th>Valuation above average %</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEV: 150 km BR</td>
<td>110</td>
<td>24,968</td>
<td>25,000</td>
<td>6560</td>
<td>20,000</td>
<td>30,000</td>
<td>41 %</td>
</tr>
<tr>
<td>EREV1: 50 km BR, 150 km FPR</td>
<td>110</td>
<td>21,168</td>
<td>22,000</td>
<td>7732</td>
<td>16,000</td>
<td>25,000</td>
<td>3 %</td>
</tr>
<tr>
<td>EREV2: 50 km BR, 300 km FPR</td>
<td>110</td>
<td>23,982</td>
<td>25,000</td>
<td>8309</td>
<td>20,000</td>
<td>30,000</td>
<td>50 %</td>
</tr>
<tr>
<td>EREV3: 100 km BR, 300 km FPR</td>
<td>111</td>
<td>28,302</td>
<td>30,000</td>
<td>7753</td>
<td>25,000</td>
<td>35,000</td>
<td>91 %</td>
</tr>
</tbody>
</table>

**Notes.** BR stands for battery range; FPR stands for full power range. One respectively two participants did not answer the items assessing valuation of the vehicle configurations. Hence, N = 111 respectively N = 110.

The *U*-tests showed that valuation for the BEV was significantly higher than for the EREV1 and significantly lower than valuation for the EREV3 (see Table 4). There was no significant difference regarding valuation between the BEV and the EREV2. Furthermore, it can be seen that valuation of the EREV3 was significantly higher than valuation for the EREV1 as well as the EREV2. There was also a significant difference between valuation of the EREV1 and the EREV2. Hence, the full power range range seems to be important for participants’ valuation, but only if there is not a significant reduction in battery range.
Does Range Matter?

Table 4

U-Tests for valuation in Euro.

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>z</th>
<th>p</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEV – EREV1</td>
<td>110</td>
<td>3800</td>
<td>6944</td>
<td>-5.21</td>
<td>&lt;.001</td>
<td>0.55</td>
</tr>
<tr>
<td>BEV – EREV2</td>
<td>110</td>
<td>986</td>
<td>7512</td>
<td>-0.46</td>
<td>.650</td>
<td>0.13</td>
</tr>
<tr>
<td>BEV – EREV3</td>
<td>110</td>
<td>-3410</td>
<td>6455</td>
<td>-5.35</td>
<td>&lt;.001</td>
<td>-0.53</td>
</tr>
<tr>
<td>EREV1 – EREV2</td>
<td>110</td>
<td>-2814</td>
<td>3227</td>
<td>-7.68</td>
<td>&lt;.001</td>
<td>-0.87</td>
</tr>
<tr>
<td>EREV1 – EREV3</td>
<td>110</td>
<td>-7210</td>
<td>6282</td>
<td>-8.84</td>
<td>&lt;.001</td>
<td>-1.15</td>
</tr>
<tr>
<td>EREV 2 – EREV3</td>
<td>110</td>
<td>-4396</td>
<td>5120</td>
<td>-8.35</td>
<td>&lt;.001</td>
<td>-0.86</td>
</tr>
</tbody>
</table>

Notes. p-values are two-tailed.

Furthermore, for each individual, we calculated whether the valuation of each specific vehicle configuration was higher than the individual’s average valuation across all vehicle configurations (see column “Valuation above average %” in Table 3). The frequencies showed that the majority of the participants valuated the EREV3 higher than their average valuation across all vehicle concepts. In addition, although the average valuation of the BEV was slightly higher than the average valuation of the EREV2, more participants would be willing to pay more than the average valuation for the EREV2 than for the BEV.

Similar to findings regarding appreciation, we also found considerable individual differences when assessing valuation. To analyze these individual differences, we created two extreme groups. This aggregation is useful because it allows side-by-side comparisons of clear proponents and clear opponents of EREVs versus BEVs. Thus, on the one hand, we have participants who would pay the most for the BEV configuration, and on the other hand, we have participants who would pay more for any of the three EREV configurations than for the BEV configuration. Data showed that 22 participants in the whole sample would pay the most for the BEV and 26 participants would pay the most for any of the three EREV
configurations. For further analyses, we call these two groups: (1) valuation pro BEV concept and (2) valuation pro EREV concept.

Considering potential differences between the two valuation groups regarding socio-demographic variables, results showed that there were no significant differences in valuation regarding age ($t(46) = -0.19, p = .849, d = -0.06$), education ($\chi^2(2) = 0.93, p = .677, w = 0.23$), household’s total income ($\chi^2(5) = 8.83, p = .110, w = 0.43; 8$ cells have expected values < 5) as well as BEV driving experience ($z = -1.77, p = .079, d = -0.17$).

In sum, regarding Q1, results showed that both EREVs as well as BEVs were highly appreciated by our sample of experienced BEV drivers, even though BEVs were appreciated slightly more than EREVs. However, participants valuated an EREV with a battery range of 100 km and a full power range of 300 km highest. Hence, the total range seems to play an important role in determining participants’ valuation, but only if there is not a significant reduction in battery range.

5.2 Examination of individual differences in acceptance (Q2)

Regarding Q2, “Do the theorized factors predict individual differences in acceptance of EREVs versus BEVs?”, we created two different group variables based on the acceptance variables as aforementioned (i.e., appreciation pro BEV/ EREV concept and valuation pro BEV/ EREV concept).

All mobility variables were checked for plausibility. In particular, participants seemed to have problems with the items $Max_{Day\text{typicalWeek}}$ and $Range_{150\text{notsufficient}}$. $Max_{Day\text{typicalWeek}}$ data points were eliminated when $Max_{Day\text{typicalWeek}}$ was smaller than $M_{Work\text{day}}$ or $M_{Week\text{end\text{day}}}$ (13 cases) and/or when $Max_{Day\text{typicalWeek}}$ multiplied by 52 weeks a year was larger than $SUM_{12\text{Month\text{as}}}$ (13 cases). In total, 26 data points of $Max_{Day\text{typicalWeek}}$ were eliminated from the analysis; thus, $N = 86$. $Range_{150\text{notsufficient}}$ data points were eliminated from the analysis if participants reported that the number of days on which a range of 300 km is insufficient
exceeds the number of days on which a range of 150 km is insufficient (the item with a range of 300 km was not relevant for the present study and was only used to test plausibility). In sum, there were three participants with such answers; thus, $N = 109$. Involving all relevant variables (i.e., appreciation, valuation, mobility needs and acceptability of RE usage), there were 81 full data sets with no missing or implausible values.

5.2.1 Mobility needs

Results of Q2.1, “Do mobility needs predict individual differences in acceptance of EREVs versus BEVs”, are shown in Table 5.

To test hypothesis H1, we analyzed $M_{\text{Workday}}$ and $M_{\text{wholeWeekday}}$. The results showed that participants who valued the EREV configurations highest (i.e., valuation pro EREV) drove on average more km both on a typical workday and a typical whole weekday than participants who reported higher valuation of the BEV configuration (i.e., valuation pro BEV), revealing significant, moderate effects. Similar tendencies were observed for appreciation (i.e., appreciation pro EREV, appreciation pro BEV), yet the effects were much weaker and insignificant. In sum, the results partially support hypothesis H1.

To test hypothesis H2, we analyzed $\text{Max}_{\text{Dayin} \text{typical Week}}$ and $\text{Max}_{\text{Dayin} \text{last Month}}$. Although data showed a trend in the expected direction (except for $\text{Max}_{\text{Dayin} \text{last Month}}$ for the appreciation groups), the $U$-tests revealed only small, insignificant effects. In sum, the results do not support hypothesis H2.

To test hypothesis H3, we analyzed $\text{Range}_{\text{150notsufficient}}$. The results showed that compared to participants who appreciated BEVs more than EREVs, participants who appreciated EREVs more stated having a greater number of days each month in which mobility needs exceed the typical battery range of 150 km. A similar pattern was observed for valuation. The observed effects were strong and significant. In sum, the results support hypothesis H3.
5.2.2 Acceptability of RE usage

Results of Q2.2, “Does acceptability of RE usage predict individual differences in acceptance of EREVs versus BEVs?”, are also shown in Table 5.

To test hypothesis H4, we analyzed \( RE_{\text{accepted}} \). The results showed that participants who reported higher valuation of the EREV configurations accepted more days in which the battery range would be insufficient and RE use would be necessary than participants who reported higher valuation of the BEV configuration, revealing a strong and significant effect. Also, appreciation was related to the acceptable number of RE use days, even though the observed effect was smaller. In sum, the results support hypothesis H4.

Table 5

(A) U-tests for Appreciation.

<table>
<thead>
<tr>
<th>Variables</th>
<th>pro EREVs</th>
<th>pro BEVs</th>
<th>Mann-Whitney-U-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>Mdn</td>
</tr>
<tr>
<td>( M_{\text{Workday}} )</td>
<td>24</td>
<td>103.3</td>
<td>90.0</td>
</tr>
<tr>
<td>( M_{\text{wholeWeekday}} )</td>
<td>24</td>
<td>89.3</td>
<td>73.2</td>
</tr>
<tr>
<td>( \text{MaxDayinTypicalWeek} )</td>
<td>21</td>
<td>205.7</td>
<td>110.0</td>
</tr>
<tr>
<td>( \text{MaxDayinLastMonth} )</td>
<td>24</td>
<td>352.9</td>
<td>300.0</td>
</tr>
<tr>
<td>( \text{Range}_{\leq 150\text{nonsufficient}} )</td>
<td>22</td>
<td>7.6</td>
<td>4.0</td>
</tr>
<tr>
<td>( RE_{\text{accepted}} )</td>
<td>24</td>
<td>5.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

(B) U-tests for Valuation.

<table>
<thead>
<tr>
<th>Variables</th>
<th>pro EREVs</th>
<th>pro BEVs</th>
<th>Mann-Whitney-U-Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>Mdn</td>
</tr>
<tr>
<td>( M_{\text{Workday}} )</td>
<td>26</td>
<td>122.1</td>
<td>115.0</td>
</tr>
<tr>
<td>( M_{\text{wholeWeekday}} )</td>
<td>26</td>
<td>110.9</td>
<td>97.1</td>
</tr>
<tr>
<td>( \text{MaxDayinTypicalWeek} )</td>
<td>21</td>
<td>198.6</td>
<td>140.0</td>
</tr>
<tr>
<td>( \text{MaxDayin12Months} )</td>
<td>26</td>
<td>801.9</td>
<td>750.0</td>
</tr>
<tr>
<td>( \text{Range}_{\leq 150\text{nonsufficient}} )</td>
<td>25</td>
<td>7.1</td>
<td>4.0</td>
</tr>
<tr>
<td>( RE_{\text{accepted}} )</td>
<td>26</td>
<td>6.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Notes. \( p \)-values are one-tailed. Different Ns caused in missing values.
6 Discussion and conclusion

The present study was conducted in order to advance understanding of individuals’ acceptance of EREVs relative to BEVs in more mature markets (i.e., markets where more customers will have had substantial experience with limited-range mobility). Moreover, we investigated whether individual differences in acceptance of EREVs versus BEVs are related to specific mobility needs (i.e., the congruence of each vehicle design with individual mobility patterns) and the acceptability of RE usage (i.e., the importance an individual ascribes to driving purely electric).

6.1 Summary of study findings

Regarding Q1, the present study showed that the general appreciation of both EREVs and BEVs was high in early adopters of EVs with previous BEV experience. However, although BEVs were appreciated slightly more than EREVs, the participants in the present study would pay the most for the EREV3 with a battery range of 100 km and a full power range of 300 km than the typical BEV with a range of 150 km. This shows that total range plays an important role for drivers who have experience with limited-range mobility. However, the valuation of the EREV2 (battery range of 50 km and full power range of 300 km) was significantly smaller than the valuation of the EREV3, indicating that potential customers do not accept a significant reduction in the battery range of an EREV.

Regarding Q2.1, results indicate that participants who had longer average daily driving distances rated acceptance of the EREV configurations higher (H1 partly supported); whereas maximum daily driving distances did not predict individual differences in acceptance of EREVs versus BEVs (H2 not supported). In contrast, the number of expected days per month that exceeds the typical BEV range of 150 km was strongly related to a higher appreciation and valuation of EREVs relative to BEVs (H3 supported), indicating that this indicator is crucial for perceived mobility congruence, and therefore, acceptance of EREVs versus BEVs.
Does Range Matter?

Regarding Q2.2, the results showed that participants who reported higher appreciation and valuation of the EREV configurations accepted RE usage on a higher percentage of days (H4 supported). Hence, differences in individual preferences regarding accepted RE usage are reflected in the acceptance of EREVs versus BEVs.

6.2 Implications of the study

Due to adaption processes towards high range mobility in the past 100 years, a widespread introduction of BEVs within the next few years seems to be challenging. The limited-range BEV is a highly incongruent product that cannot easily be integrated into existing schemata of automobility. However, the results of the present study provide some evidence that schemata of automobility might be adapted with increasing experience with limited-range mobility. Participants of our sample of experienced EV users did not solely prefer an EV with a high total range. Instead, many participants showed a high valuation for vehicle configurations with reasonable ranges. Moreover, participants’ appreciation and valuation of vehicle concepts varied based on their mobility needs. Hence, the results suggest that in more mature markets, where more people will likely have more experience with limited-range mobility, and therefore, a more precise understanding of their own mobility needs, car buyers will tend to choose vehicle concepts and configurations based on their specific fit to individual mobility patterns.

The most important indicator of users’ acceptance of EREVs relative to BEVs seems to be the number of days per month that the driving distance is estimated to exceed the typical BEV range. This makes also intuitive sense from a personal utility perspective (i.e., utility maximization) because such an indicator is directly related to the critical days on which mobility needs are higher than typical BEV range. Hence, measures of central tendencies (i.e., average or maximum daily driving distance) may be not optimal for predicting individual differences in acceptance of EV concepts, whereas approaches, such as the work of
Pearre et al. (2011) appear more appropriate for assessing sufficient EV range (i.e., especially for estimations that should be based on data from national panel surveys or similar data sources).

Often, from both a policymaking and a vehicle design perspective, it is critical to determine which indicators of mobility needs can be used to estimate the likelihood that different EV concepts will be accepted by potential customers (i.e., to understand market potential and prospective user groups). The present study provides empirical evidence suggesting that the number of days per month in which mobility requirements exceed the typical BEV range should be considered as a key variable.

With regard to the importance of driving purely electric, the study findings indicate that a high total range alone is not sufficient for the acceptance of EREVs. In the present study a reduced battery range was related to a reduced willingness to pay. Thus, for many potential customers it seems to be also important to drive a substantial portion of the distances purely electric.

Furthermore, the results indicate that acceptability of RE usage, and therefore, the importance attached to driving purely electric, predicts individual differences in the acceptance of EREVs versus BEVs. Higher importance attached to driving purely electric predicts lower acceptance of EREVs relative to BEVs. Interestingly, individuals seem to perceive the RE considerably differently. While some individuals prefer to use the RE only for rare trips; others prefer to use the RE for nearly all trips that are longer than the most typical trips.

In sum, the findings suggest that the number of days per month expected to exceed typical BEV range and the acceptability of RE usage can be used to predict which vehicle concept will likely be accepted by potential customers in more mature markets.
6.3 Implications for other countries

Although the present study was conducted in Germany, we argue that our findings might also have some validity in other countries. It is important to note that market development follows similar processes and is currently at a similar “stage” in different countries. For example, in the year 2013, the proportion of EVs in the total number of new vehicle registrations was 0.2% in Germany, 0.2% in Great Britain and 0.3% in Denmark (Statista, 2014). Hence, because of the similarity of these countries regarding EV market diffusion, similar studies in other countries can be expected to arrive at relatively similar results and conclusions.

Furthermore, it is likely that the demographic characteristics of potential early adopters of alternative fuel vehicles are relatively similar in different countries. For instance, research indicates that early adopters are predominantly young or middle-aged (e.g., Plötz, Schneider, Globisch, & Dütschke, 2014; Hidrue, Parsons, Kempton, & Gardner, 2011; Wietschel et al., 2012), male (e.g., Plötz et al., 2014; Wietschel et al., 2012; Anable, Skippon, Schuitema, & Kinnear, 2011; O’Garra, Mourato, & Pearson, 2005;) and well-educated (e.g., Wietschel et al., 2012; Anable et al., 2011; Hidrue et al., 2011; O’Garra, Mourato, & Pearson, 2005).

Moreover, Vilimek and Keinath (2014) showed in their report on the international MINI E field trials (carried out in the United States, Germany, the United Kingdom, France, Japan and China) that satisfaction with BEV range was between 77% (China) and 84% (France), indicating that early adopters of EVs across countries are still relatively similar in their subjective evaluation of limited range. For these reasons, the results of the present study might generalize to countries beyond Germany.
6.4 Critical evaluation and further research

The present research represents a first attempt to examine acceptance of EREVs relative to BEVs in more mature markets. However, several limitations of this research have to be considered.

First, we used appreciation and valuation to assess the acceptance of EREVs relative to BEVs which represents a minimalist assessment of acceptance. However, this method was deemed necessary because potential EV customers with BEV experience are rare, which necessitates the use of a protocol that places minimal burden on participants (i.e., economical questionnaire design). Future studies should utilize a more comprehensive assessment of acceptance.

Furthermore, we investigated participants’ perceived mobility needs. Therefore, it is possible that these estimates are biased. However, it is likely that potential customers base their purchase decisions on their perceived mobility patterns rather than on their actual, precise needs. Hence, perceived mobility needs are likely an important predictor of consumer preferences regarding range configurations.

Moreover, because of self-selection biases the sample might not be representative of the German population of car buyers. However, the goal of the study was to examine potential early adopters of EVs, not the general population of car buyers. The majority of the sample was male, middle-aged and well-educated which is typical for early adopters of EVs (see e.g., Plötz et al., 2014; Wietschel et al., 2012, Vilimek & Keinath, 2014). But, because of the focus on this target group, the study bases on a relatively small sample. Further studies should target to investigate larger samples.

Finally, because several participants were recruited from the study “BMW ActiveE Leipzig – long-distance commuters”, there was a considerable portion of participants who had relatively high daily mobility needs. Although it is particularly relevant to examine whether customers in more mature markets with higher mobility needs would prefer EREVs relative
to BEVs, further research with potential customers who have other mobility profiles (i.e., mostly urban mobility) is clearly needed.

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Does Range Matter?


