

# What drives range preferences in electric vehicle users?

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## ABSTRACT

While research has shown that limited-range electric vehicles (EVs) satisfy the range needs of a sizeable share of the driving population, car buyers seem to prefer vehicles with high available range. The objective of the present research was to advance understanding of the factors that influence the range preferences of potential EV customers who had the opportunity to test an EV. Data from 79 participants who had driven an EV for 3 months was assessed in a field study setting. Range preferences of those users were found to be substantially higher than their average range needs. Regression analyses indicated that higher average range needs, higher range of the driver's familiar combustion vehicle (CV), and greater experienced range anxiety were related to higher range preferences. Furthermore, we found that range preferences decreased over the first 3 months of EV use. Finally, indicators of average range needs were more strongly associated with range preferences as EV experience increased. Thus, only customers with EV experience seem to rely on accurate estimates of their range needs when constructing their range preferences. Implications for strategies aimed at enhancing customer appraisal of limited range mobility and determining optimal EV range are discussed.

**Keywords:** range, electric vehicle, preferences, mobility needs, sustainability, field study

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## 1 INTRODUCTION

What is the optimal range of an electric vehicle (EV)? This question is consistently raised in conjunction with efforts to develop sustainable and marketable EVs, and has yielded substantially disparate answers: Evidence suggests that range needs of a sizeable share of the current car fleet could be covered with 100-mile range per charge (Pearre et al., 2011). However, potential customers have repeatedly been found to prefer vehicles with considerably higher available range (Dimitropoulos et al., 2011).

This paradoxical disparity has been noted frequently in the literature (e.g., Giffi et al., 2011; Kurani et al., 1994) and various explanations for high range preferences have been suggested, such as inaccurate conceptions of usual mobility needs (Kurani et al., 1994), high anchors for estimating required range stemming from experience with combustion vehicles (CVs; Kurani et al., 1994), range anxiety (Nilsson, 2011), and lack of experience with limited range mobility (Kurani et al., 1994). However, research that examines these assumptions is lacking. Moreover, it has been argued that examining the range preferences of respondents without EV experience, as most previous studies did, may not be a useful approach for determining truly marketable EV range in more mature markets. Accordingly, researchers have recommended that studies of range preferences should include samples of drivers with EV experience (Kurani et al., 1994).

The objective of the present research was to increase understanding of range preferences of potential EV customers with practical EV experience and of the factors driving those preferences. To this end, a field trial approach was applied in which 79 EV users drove an EV for 3 months and provided extensive objective and subjective data. We studied the disparity between range needs and range preferences and examined potential explanatory variables for range preferences. This research aims to provide data needed to guide the development of measures for reducing the gap between range needs and range preferences, and to support customers in selecting more sustainable EV setups.

## 2 BACKGROUND

### 2.1 The EV range paradox

The battery of a fully electric vehicle is a precious resource. Its efficient layout is critical for environmental utility, as it uses a sizeable amount of energy and rare mineral resources for production and, consequently, has a substantial impact on the ecological footprint of an EV (McManus, 2012). Moreover, more battery capacity results in a higher purchase price and, thus, lower affordability and cost-effectiveness (Neubauer et al., 2012). Hence, from a sustainability perspective, the optimal EV range is the smallest sufficient range.

Determining sufficient EV range has been the focus of numerous studies examining data on travel behavior. For example, findings based on representative data of everyday automobile usage in Germany show that on a typical day, 95% of cars on the road travel less than 100 km (Öko-Institut, 2011). Similar figures have been reported for other European countries (Bunzeck et al., 2011). However, this criterion has been criticized for underestimating range needs, because a vehicle that can cover an average, or typical, day will not satisfy user needs on many days (Greene, 1985). Consequently, other indicators have been studied, for instance, the longest daily travel distance per year (Greene, 1985; Pearre et al., 2011), per week (Chlond et al., 2012) or on a certain energy critical day (Sammer et al., 2011). Still, these studies show that the currently common 100-mile range of EVs is sufficient for a sizeable share of the car driving population (see overview in Table 1).

Table 1: Results from previous studies on range needs.

Study	Sample	Results
infas and DLR, 2010	N = 60,713; representative for German population (MiD).	On average, people in Germany travel 39 km per day (one-day travel diary).
Öko-Institut, 2011	Analysis of data collected in MiD 2008 (infas and DLR, 2010).	80% of vehicles travel less than 50 km per day, 95% less than 100 km. On average, 12 trips per year exceed a driving range of 160 km.
Zumkeller et al., 2011	N = 1800; representative for German population (MOP).	On average, people in Germany travel 41 km per day (7-day travel diary).
TÜV Rheinland, 2011	N = 1000; considered representative for Germany.	On average, 91% of German respondents drive less than 100 km per day, 61% of them less than 50 km.
Bunzeck et al., 2011	N = 1899 respondents from 7 EU countries.	61% of European participants drive less than 100 km per day, 24% even less than 20 km. 15% drive more than 150 km per day.
Giffi et al., 2011	N > 13,000 respondents from 17 countries worldwide.	78% of German respondents drive less than 80 km on a typical weekday.
Pearre et al., 2011	N = 484 cars in Atlanta, Georgia greater metropolitan area.	The mean daily driving distance is 45 miles (median: 30 miles). On average, the daily driving range exceeds 100 miles on 23 days per year and 150 miles on 9 days per year. An EV with 100 miles driving range could fully satisfy 9% of the drivers.
Krumm, 2012	N = 150,147 US households (representative).	The mean daily distance of US drivers on a random weekday is 38.4 miles. An EV with 60 miles driving range would satisfy 83%, while 80 miles would be suitable for 90% and 120 miles for 95% of the US drivers.

However, since acceptance and marketability are fundamental factors of sustainability of EVs, optimal range depends not only on range needs (objectively sufficient range), but also on customer preferences. In previous EV range preference studies, two major methodological approaches have been used (see also Table 2). First, numerous studies used the direct stated preference approach, which requires respondents to indicate a numerical range value that matches a certain utility level (e.g., minimum required range for purchase or minimum acceptable range). For instance, stated preference data for Germany indicate that the average customer wants a range of approximately 340 km (Bunzeck et al., 2011 [328 km]; VDE, 2010 [353 km]). Studies on the European (Bunzeck et al., 2011 [308 km]) and world-wide level (Bronchard et al., 2011 [437 km]) report similar or higher figures.

Second, numerous studies have employed the indirect hypothetical approach with choice-based conjoint analyses (i.e., discrete choice experiments) or contingent ranking tasks. A recent meta-analysis of 31 studies examining customer valuation of driving range (Dimitropoulos et al.,

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2011) reveals that the compensating variation for increasing range from 100 to 350 miles would be 16,200 US\$. The authors conclude that EVs with a 100-mile range would have to be priced 50% cheaper than comparable CVs to be competitive. A similar pattern of results is revealed by Daziano's (2013) analysis of choice experiment data. Using the function of range equivalency (i.e., the range at which an EV is perceived to be as attractive as a benchmark vehicle), the author concludes that an EV would only be perceived as equivalent to a conventional gasoline vehicle if its driving range were 330 miles, when cheaper EV operating costs are not considered. If operating costs are factored into the analysis, this estimate would drop to 180 miles (assuming the same purchase price for an EV and a gasoline vehicle).

All in all, these results reveal a substantial discrepancy between range preferences and sufficient range. We refer to this as the "range paradox" in EVs. However, will this discrepancy also hold for future markets that consist of more potential customers who already have experience with limited range mobility? And which factors may influence range preferences in such contexts? Answering these questions may help to yield better estimates of marketable range and aid in the development of strategies to further reduce the range discrepancy.

Table 2: Results from previous range preference studies.

Method	Study	Sample	Results
<b>Direct approach</b>	VDE, 2010	<i>N</i> = 1000; German residents >14 years of age (representative).	The average German resident considers 353 km driving range to be acceptable.
	ADAC, 2013	<i>N</i> = 803 (2011) vs. 507 (2013) ADAC members.	In 2011 74% of ADAC (German automobile club) members desired an EV range of more than 200 km. In 2013, this decreased to 50%.
	Bunzeck et al., 2011	<i>N</i> = 1899 respondents from 7 EU countries.	European respondents require 308 km driving range on average; for German consumers, this figure is somewhat higher (328 km).
	Giffi et al., 2011	<i>N</i> > 13,000 respondents from 17 countries worldwide.	60% of German respondents want an EV to have more than 320 km driving range before they would consider a purchase.
	Bronchard et al., 2011	<i>N</i> = 7003; representative for the general population of 12 countries worldwide.	In order to consider purchasing an EV, people worldwide would prefer to have a range of at least 437 km.
	Zpryme, 2010	<i>N</i> = 1046; representative for US drivers.	On average, US drivers consider 294 miles driving range to be acceptable.
<b>Indirect Approach</b>	Dimitropoulos et al., 2011	Meta-analysis of 31 discrete choice and contingent ranking studies.	Compensating variation to extend driving range from 100 to 150 miles is 3500 US\$ (16,200 US\$ from 100 up to 350 miles). Willingness to pay for one-mile increase in driving range between 47 and 64 US\$  An EV is perceived as attractive as a gasoline vehicle if its driving range reaches 330 miles. However, if operating costs are integrated into the analysis, the estimate decreases to 180 miles (assuming comparable prices of EV and gasoline vehicle).
	Daziano, 2013	<i>N</i> = 500 California residents.	Willingness to pay for an increase of driving range reaches its maximum in lower range areas, i.e., consumers are highly motivated to avoid low EV driving ranges.
	Hoen & Koetse, 2012	<i>N</i> = 1802 Dutch drivers.	

## 2.2 The construction of EV range preferences

In order to address the research question regarding which factors might drive range preferences, it is important to understand that preferences often result from a construction process that is vulnerable to various psychological biases (Slovic, 1995). Most importantly, preferences are known to be driven by what comes to mind first (Warren et al., 2011), meaning that the information that is most accessible in memory in a given situation will have the most pronounced impact on the resulting preferences. Accessibility is increased by extensive activation of information (Schwarz, 2007) and by higher associative strength (e.g., caused by more frequent simultaneous activation) between information and the object under judgment (Collins and Loftus, 1975). Hence, if people are

very frequently exposed to certain numerical values in connection with driving range, it is likely that those values also drive their range preferences (i.e., act as reference points).

Second, this information more strongly influences a preference that is perceived to be more plausible, relevant, or diagnostic (Warren et al., 2011). Hence, if people have two equally accessible information sources when constructing their range preferences, they will likely more strongly rely on the more diagnostic one (e.g., the more precise indicator of their mobility needs).

Third, affective associations will influence all of these processes. For example, the experience of negative affect (e.g., fear) in conjunction with the object under judgment will lead to more risk-averse preferences (Peters, 2006; Weber and Johnson, 2009). All in all, we expect that these general dynamics in preference formation will also play a role in range preference construction.

### **2.3 Hypotheses regarding factors that drive range preferences of EV users**

(H1) Research has revealed a discrepancy between range preferences and usual range needs in people without EV experience (see section 2.1), indicating that people might desire certain range safety buffers. Similar safety buffers have also been identified in range utilization behavior of experienced EV users (Franke et al., 2012c; Franke and Krems, 2013). Consequently, we also expect range preferences of *experienced* EV users to be higher than their usual range needs.

(H2) It has been argued that people typically do not hold highly accessible, accurate representations of their usual range needs, as they do not deal with daily distance budgets in using CVs (Kurani et al., 1994). However, when users deal with limited-range electric mobility, they have to manage daily distance budgets and develop heuristics to plan their journeys (Franke et al., 2012c). This should lead to more accessible, precise representations of usual range needs. Hence, it seems likely that experienced EV users use relatively precise estimates of their usual range needs to construct range preferences. Consequently, we expect a positive relationship between usual range needs and range preference in EV users.

(H3) It has repeatedly been argued that people are so adapted to high-range, single-mode CVs that they likely base their judgments of acceptable vehicle range on these highly accessible familiar values (Giffi et al, 2010; Kurani et al., 1994). Indeed, the status quo is known to be a powerful reference point in preference construction (Samuelson and Zeckhauser, 1988). Consequently, we expect a positive relationship between familiar CV range, hereafter referred to as CV performant range (cf. Franke and Krems, 2013), and range preferences.

(H4) Range anxiety has repeatedly been proposed as a factor that promotes high range preferences (Nilsson, 2011). Given the research demonstrating the impact of negative affect on judgment (see section 2.2.), it seems reasonable that experienced range anxiety may be associated with higher range preferences. Consequently, we expect a positive relationship between experienced range anxiety and range preferences of EV users.

(H5) When considering (H2) from a longitudinal perspective, it can be expected that as EV experience increases, precise representations of usual range needs will be more strongly incorporated into range preference construction. Consequently, we expect that as experience increases, the relationship between range needs and range preferences will strengthen.

(H6) Taken together, these hypotheses suggest that experienced EV users should prefer lower range setups than inexperienced users. This is also supported by the finding that the need for safety buffers decrease with EV experience (Franke et al., 2012b). Consequently, we expect that users' range preferences at post-test (i.e., after driving the EV for some time) will be lower than at pre-test (i.e., before receiving the EV).



## 3 METHOD

### 3.1 Field trial setup

The present research was part of a large-scale EV field trial in the metropolitan area of Berlin, Germany. This trial was set up by the BMW Group and Vattenfall Europe, and funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. It was part of an international EV field trial (Vilimek et al., 2012). The EV was a converted MINI Cooper with 168 km range under normal driving conditions (miniusa.com, 2012). Users had access to public and private charging stations. Two consecutive 6-month user studies (S1 and S2) included 40 participants each. Data were collected prior to receiving the EV (T0), after 3 months (T1), and after 6 months (T2). Data for the present study came only from T0 and T1, 79 users completed T0 and T1. Further details on methodology are reported elsewhere (Cocron et al., 2011; Franke et al., 2012a).

### 3.2 Participants

Eighty participants were selected from more than 1000 applicants recruited via an online screening instrument that was announced in both print and online media. Requirements for participation were residence in the Berlin metropolitan area, willingness to pay a monthly leasing rate of 400 Euros, and to install a private charging station. Additional criteria aimed to increase variance in basic socio-demographic (e.g., age, gender, education) and mobility-related variables (e.g., mileage, vehicle fleet). Despite these efforts, our sample was still restricted in variance on certain basic socio-demographic characteristics compared to the general population of automobile drivers in Germany (i.e., the average German car driver). The sample can rather be assumed to represent early adopters of EVs in German metropolitan areas.

The 79 users in the sample who completed T1 had a mean age of 49 years. Eighty-five percent were male, 76% had obtained at least a university of applied science entrance qualification (nearly all of these had a university degree), 10% reported a monthly net household income below 3.000 Euro, and the average household size was 2.9 persons (47% of households had <3 persons). To

better understand the differences between this sample and the population of German car drivers, we analyzed data from the representative large-scale survey “Mobility in Germany 2008” (Mobilität in Deutschland, MiD; infas and DLR, 2010). We included only those persons who had access to a car at any time (72 % of the persons living in Germany) and were at least 17 years old. These had a mean age of 42 years, 51% were male, 40% had at least a university of applied science entrance qualification, 65% had a monthly net household income below 3.000 Euro, and the average household size was 2.4 persons (64% of households had <3 persons). Hence, our sample is older, more affluent, more educated, and includes more male persons than the general population of German car drivers. In terms of average-day travel distances in a typical week our sample had even higher values ( $M_{7D} = 58.76$  km, only  $N = 66$ , see section 3.3.2) than the German average of 40.6 km (Zumkeller et al., 2011).

### 3.3 Measures

#### 3.3.1 Range preferences

Two open-ended, stated preference items asked users to directly indicate their preferred range value underlying two different levels of the utility function. For contexts where incentive-aligned methods are not applicable, it has been shown that single-item, open-ended question formats can be as valid as choice-based conjoint analyses (Miller et al., 2011). Items were framed to the real available range of the test EV. The item text was: (1) “Which EV range would you consider to be quite short, but just acceptable?” (termed “minimum acceptable range”, conceptually similar to a reservation price), and (2) “Which EV range would you consider to be just right and, therefore, appropriate?” (termed “appropriate range”). Both items were administered at T1. In S2, minimum acceptable range was also assessed at T0. This and all following variables were checked for univariate outliers in accordance with Grubbs (1969). One case was an outlier on both T1 variables ( $z > 4.96$ ), hence  $N = 78$ , and one case was an outlier on T0 minimum acceptable range in S2 ( $z = 3.49$ ), hence  $N = 39$ . The Kolmogorov-Smirnov (KS) test was used to test for violations of normality for all score

variables. As one would expect for range preferences (Dimitropoulos et al., 2011), log transformation was needed for the data to fit a normal distribution.

### **3.3.2 Range needs**

Data on range needs were derived from the T0 travel diary, which was a person-based 1-week record of all trips, including all modes of transport. Based on previously proposed range need indicators (see section 2.1), we computed the mean ( $M_{7D}$ ) and maximum ( $Max_{7D}$ ) daily travel distances for the 7-day week (7D),  $N = 66$  because of 11 cases with missing data and 2 outlier cases ( $z > 3.29$ ). We also asked users to mark a typical day (TD) and computed the total distance traveled on that day ( $Sum_{TD}$ ),  $N = 56$ , as only 57 users marked their TD and there was one outlier ( $z > 6.38$ ). Log transformation was needed to fit a normal distribution.

### **3.3.3 Performant range**

Users' CV performant range was assessed at T0 only in S2 with one item ( $N = 40$ ): "How far does one full tank usually last (based on annual average) before the tank is completely emptied in your most used car (km)?"

### **3.3.4 Range anxiety**

Range anxiety was assessed with two items at T1 ( $N = 79$ ): (1) "I am more concerned about the range in the EV than I would be in a conventional vehicle with an internal combustion engine." (2) "While driving, I was often worried about the range." Cronbach's Alpha was .62.

## 4 RESULTS

We analyzed our data using *t*-tests and regression analyses. Assumptions for *t*-tests were satisfactorily met. Assumptions for regression analyses (Stade et al., 2011) were satisfactorily met, except for some non-normal distributions, that were resolved with log-transformation, and some single outlier cases, residual  $z$ -value  $> |1.96|$ . Urban and Mayerl (2008) recommended presenting results with and without these outliers. To aid readability, results without outliers are presented only if their significance or effect size magnitude differed considerably from results with outliers. To test our directional hypotheses, we used one-tailed tests. The descriptive statistics for the variables used in the analyses are depicted in Table 3.

Table 3: *Descriptive statistics for variables used in the analyses.*

	<i>N</i>	<i>M</i>	<i>Mdn</i>	<i>SD</i>	<i>P25</i>	<i>P75</i>
Range preferences						
Minimum acceptable range T1	78	135.9	120.0	60.1	100.0	155.0
Minimum acceptable range T0	39	144.9	120.0	59.6	100.0	150.0
Appropriate range T1	78	214.5	200.0	89.8	150.0	262.5
Range needs						
$M_{7D}$	66	60.1	45.6	38.3	35.8	66.7
$Max_{7D}$	66	152.7	83.5	150.9	63.8	161.3
$Sum_{7D}$	56	46.7	45.5	26.0	32.1	55.1
CV performant range	39	607.8	600.0	201.2	480.0	700.0
Range anxiety	79	3.4	3.5	1.0	3.0	4.0

*Note.* The maximum available sample (*N*) is analyzed for each variable. *N* can be smaller when relating two variables in an analysis. Therefore key descriptive statistics are repeated for the final *N* used in the analyses (e.g., section 4.6). *P25/P75* = 1<sup>st</sup>/3<sup>rd</sup> quartile.

### 4.1 Discrepancy between range preferences and range needs

All difference score variables, except those including  $Max_{7D}$ , were normally distributed (KS-test  $p > .05$ ). Therefore, *t*-tests were computed with untransformed variables, except for tests including  $Max_{7D}$ , which used log-transformed variables.

In support of H1, range preferences were generally found to be substantially higher than average daily range needs in our sample of experienced EV early adopters. The minimum acceptable and appropriate range values were significantly ( $p < .001$ ) higher than average ( $M_{7D}$ ) and typical ( $Sum_{7D}$ ) daily distance, with effect sizes between  $d = 1.24$  and  $d = 1.95$  (on average  $d = 1.61$ ). The difference between maximum daily travel distance ( $Max_{7D}$ ) and appropriate range was also strong ( $d = 0.80$ ,  $p < .001$ ), but the difference between  $Max_{7D}$  and minimum acceptable range was weak and insignificant ( $d = 0.20$ ,  $p = .060$ ). Cumulative distributions of  $M_{7D}$ ,  $Max_{7D}$ , and minimum acceptable range are depicted in Figure 1. On average,  $M_{7D}$  was 58.76 km ( $SD = 37.40$ ,  $Mdn = 44.99$ ), and  $Max_{7D}$  was 149.30 km ( $SD = 149.24$ ,  $Mdn = 81.00$ ), whereas minimum acceptable range was 135.13 km ( $SD = 57.93$ ,  $Mdn = 120.00$ ).

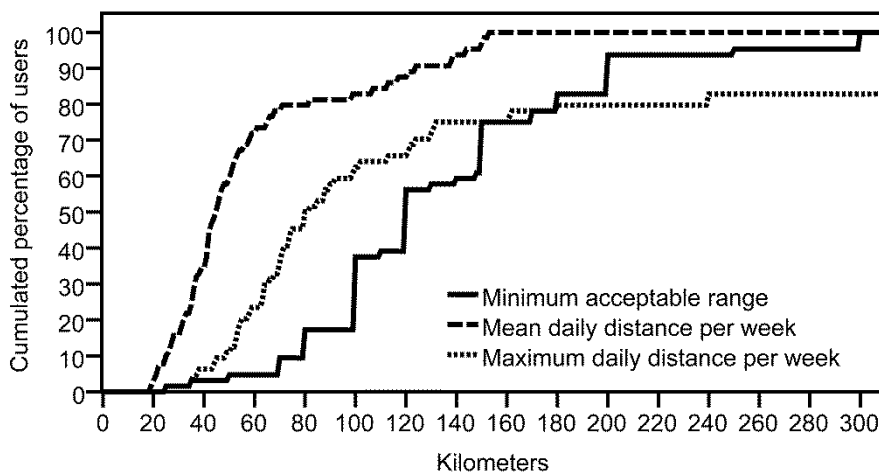


Figure 1: Cumulative distributions of  $M_{7D}$  and  $Max_{7D}$  and T1 minimum acceptable range ( $N = 64$ ).

#### 4.2 Objective range needs as predictor for range preferences

In support of H2, usual range needs were moderately, positively associated with range preferences of experienced EV users (see Table 4). Hence, experienced EV users indeed seem to incorporate range needs in range preference construction. There were no differences in explanatory power between  $M_{7D}$  and  $Max_{7D}$ . Yet, the typical day measure ( $Sum_{7D}$ ) was less effective in predicting preferred range. Hence, it seems that multi-day range need indicators are required to estimate an individual's preferred EV range.

Table 4: *Range needs as predictor of range preferences*

	<i>N</i>	$\beta$	<i>p</i>	$R^2_{adj}$
<b><i>M</i><sub>7D</sub></b>				
Minimum acceptable range	65	.31	.006	.08
Appropriate range	65	.27	.014	.06
<b><i>Max</i><sub>7D</sub></b>				
Minimum acceptable range	65	.33	.003	.10
Appropriate range	65	.31	.005	.08
<b><i>Sum</i><sub>TD</sub></b>				
Minimum acceptable range	56	.22	.053	.03
Appropriate range	56	.24	.040	.04

*Note.* *P*-values are one-tailed.

### 4.3 CV performant range as predictor of range preferences

In support of H3, the performant range of the participants' most used CV was found to be moderately, positively associated with range preferences (i.e., significant effect for all variables without outliers, see Table 5). It seems unlikely that the CV range effect is caused by pre-existing higher range needs that lead to ownership of higher range CVs, as the relationship between these two variable sets was relatively weak (average  $r = .14$ ).

Table 5: *Familiar CV performant range as a predictor of range preferences*

	<i>N</i>		$\beta$		<i>p</i>		$R^2_{adj}$	
Minimum acceptable range	39	<i>37</i>	.19	<i>.32</i>	.125	<i>.029</i>	.01	<i>.07</i>
Appropriate range	39	<i>37</i>	.27	<i>.33</i>	.047	<i>.024</i>	.05	<i>.08</i>

*Note.* Results after outlier exclusion are given in italics, *p*-values are one-tailed.

#### 4.4 Range anxiety as predictor of range preferences

In support of H4, range anxiety was positively associated with experienced EV users' range preferences (see Table 6). Effect sizes were (almost) moderate. Further, range anxiety did not appear to be a proxy variable for range needs (higher range needs = more experience of range anxiety), as these two variable sets were only weakly correlated, and in a negative direction (average  $r = -.12$ ). This increases the likelihood that individual differences in range anxiety are driven by different subjective experiences of similar range situations, rather than different exposure to critical range situations.

Table 6: *Range anxiety as predictor of range preferences*

	<i>N</i>		$\beta$		<i>p</i>		$R^2_{adj}$	
Minimum acceptable range	78	73	.28	.36	.007	.001	.07	.12
Appropriate range	78		.27		.009		.06	

*Note.* Results after outlier exclusion are given in italics, *p*-values are one-tailed.

#### 4.5 Effect of practical EV experience on the relationship between range needs and range preferences

In support of H5, usual range needs were moderately associated with range preferences of experienced EV users (T1), yielding a significant effect, but were not associated with range preferences of the same users before EV experience (T0) (see Table 7). As a direct test of H5, we tested whether the correlation between  $M_{7D}$  and T0 minimum acceptable range ( $r_{T0}$ ) was stronger than the correlation between  $M_{7D}$  and T1 minimum acceptable range ( $r_{T1}$ ), according to Meng et al. (1992). This test revealed a significant difference ( $p = .040$ , for  $Max_{7D} p = .025$ ), indicating a stronger relationship with increasing EV experience.

Table 7: Range needs as predictor of range preferences

	<i>N</i>	$\beta$	<i>p</i>	$R^2_{adj}$
<b><i>M</i><sub>7D</sub></b>				
T0: Minimum acceptable range	35	.14	.204	-.01
T1: Minimum acceptable range	35	.45	.003	.18
<b><i>Max</i><sub>7D</sub></b>				
T0: Minimum acceptable range	35	.07	.340	-.02
T1: Minimum acceptable range	35	.42	.006	.15

Note. *P*-values are one-tailed.

#### 4.6 Effect of practical EV experience on range preferences

In support of H6, minimum acceptable range was found to be higher at T0 ( $M = 144.87$  km,  $SD = 59.64$ ) than at T1 ( $M = 123.97$  km,  $SD = 60.69$ ), revealing a relatively small ( $d = .32$ ) but significant effect,  $t(38) = -2.02$ ,  $p = .025$ . Untransformed variables were used, as the difference score T0–T1 could be assumed to be normally distributed. However, a similar result was obtained with log-transformed variables,  $d = .45$ ,  $t(38) = -2.84$ ,  $p = .004$ .

## 5 DISCUSSION

The present research sought to better understand factors that influence range preferences in potential EV customers with EV experience. In general, our assumptions were supported: (H1) Range preferences were found to be substantially higher than typical and average daily range needs, but not much higher than weekly maximum daily range needs. (H2) Usual range needs were positively related to range preference of experienced EV users. (H3) Familiar CV performant range was associated with higher range preferences. (H4) Experienced range anxiety was associated with higher range preferences. (H5) Usual range needs were more strongly associated with range preferences with increasing EV experience. (H6) Range preferences decreased with EV experience.



### 5.1 Implications for understanding and resolving the EV range paradox

The discrepancy between average range needs and range preferences in our study is consistent with previous findings (see section 2.1); though, our effects appear smaller than those reported in previous studies. This might be partially attributable to the decrease in range preference associated with increased EV experience (H6), but it might also partly be attributable to our sample of early adopters, who are known to accept potential usage barriers more readily (Rodriguez and Page, 2004). Hence, the discrepancy between range needs and range preferences might be larger in the future general population of experienced EV drivers than was observed here. However, given that there are some indications of decreasing EV range preferences in the general population over the last several years (see study of ADAC, 2013 reported in Table 2), this might also not be the case. Importantly, our findings indicate that early EV buyers may not, on average, request exaggerated range setups, because their minimum acceptable range was similar to their weekly maximum daily range needs.

Our findings suggest that average and maximum usual range needs only act as a reference point in preference construction for experienced EV drivers. The weak effect for inexperienced drivers is consistent with previous research (Bunzeck et al., 2011). However, is it really plausible that potential customers without EV experience do not anchor preferences on their range needs at all? It might be that they do not use *accurate* estimators of their range needs; instead, they may only use highly accessible indicators, such as a critical destination or most recent holiday trip, which do not accurately represent usual range needs. Future research identifying these alternative reference indicators in people without EV experience may help to inform strategies for reducing range discrepancy by, for example, fostering users' understanding of the low diagnostic value of certain highly accessible range need indicators. It might also be possible to establish accurate representations of range needs in users without 3 months of limited range mobility experience. However, filling out a travel diary alone is likely not sufficient to accomplish this objective, as users also did this before the T0 range preference assessment in the present study and there was no

indication that participants relied on those recorded values. Yet, providing detailed individual feedback on the results of such a diary could already be sufficient for producing a measurable effect on range preferences.

From a methodological perspective, these findings also suggest that collecting data on travel patterns over a 1-week period is sufficient to derive meaningful estimates of average range preferences in future EV markets with more experienced users. The necessity of using multiple-day, instead of single-day data, to derive meaningful estimates of optimal range is supported by the high correlation between multiple-day range need scores and range preferences and the relatively weak correlation between the typical-day range needs and range preferences.

The obtained relationship between experienced CV range and range preferences indicate that familiar vehicle range likely acts as a reference point in range preference construction. However, based on our results, it seems unlikely that only a few months of driving a limited-range vehicle will replace the representation of high-range CVs, which users have experienced for years as the status quo of vehicle range. This should be true, at least, when users sometimes still use a conventional car, as in our study.

Range anxiety is another moderator variable that should be taken into account when considering strategies to reduce the range discrepancy. People who experience more (anticipated) range anxiety may need more support in coming to view lower range values as acceptable. An important next step will be to better understand the psychological variables that influence range anxiety.

Finally, the decrease in range preference over the first 3 months of usage suggests that practical experience with limited range mobility could play an important role in increasing acceptance and purchase intentions. This is also supported by related research that has found an increasing perceived fit between mobility needs and EV mobility resources over the first 3 months of EV experience (Franke et al., 2012b). However, the potential of short-term experience on range

appraisal has yet to be quantified because adaptation to EV range seems to take several weeks (Pichelmann et al., 2013). It might be that this time of adaptation (i.e., the learning process) can be shortened, for example, by motivating and supporting users to actively explore and exhaust the range. This could be achieved with advanced driver information and assistance systems that help users to extend the range and reduce uncertainty regarding the sufficiency of the remaining range for upcoming trips. A critical task for future research will be to examine the changes (i.e., adaptation effects) in range preferences that are caused by EV experience more in depth.

## 5.2 Critical evaluation of study design and findings

The present study was among the first to examine factors influencing range preferences of potential EV customers who had experience using a realistic electric mobility system. In interpreting the results, several critical issues must be taken into account. Given the field study research design, inferences about causal relationships cannot be easily drawn. Future studies should be conducted to determine whether the associations reported here are causally related. Moreover, replication studies with larger sample sizes are needed to test for the robustness of the present results.

Furthermore, our study results are based on a specific sample of early adopters of EVs, who are likely not representative of all car buyers. However, we believe that understanding this target group is of essential importance as it represents a wellspring for EV market penetration. Moreover, the factors influencing range preference observed in this sample of experienced users may also generalize to more mature markets, which include fewer first time buyers and more experienced EV drivers.

Finally we did not take into account several factors that affect mobility resources in an electric mobility system, such as recharging infrastructure (i.e., density and recharging time) and user access to other mobility options. These elements of an electric mobility system have the potential to act as technical safety buffers, facilitate coping with limited EV range, and therefore potentially

leading to lower range preferences. Future research should empirically test the effects of these factors on range preferences.

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