Usage patterns of electric vehicles: A reliable indicator of acceptance? Findings from a German field study

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ABSTRACT

Against a background of growing CO_2-emissions, climate change and limited oil resources, electric vehicles (EVs) are considered an essential factor towards successfully reduced air pollution and achieving more independence from oil. To reach these goals, high acceptance and increased usage rates of EVs among the public are essential. Therefore the identification of factors influencing acceptance as well as the development of strategies to improve acceptance are necessary pre-conditions for the successful distribution of EVs.

One major objective of the current study was to develop methods to measure acceptance of EVs and factors of influence while participants use the EV in everyday life. In a field trial, 40 participants drove a MINI E in the metropolitan area of Berlin for a period of 6 months. Self-monitored mobility behavior is a promising variable for the validation of subjective data concerning acceptance. For this reason, the relationship between acceptance measured via questionnaires and mobility patterns is in the focus of this research. Participants showed positive attitudes towards and high usage intensity of EVs during the whole study period, but only isolated correlations between the different variables were significant. Long-term experience with an EV proved to have a significant impact on acceptance. Furthermore, environmental concerns and attitudes measured before driving an EV on a regular basis turned out to be significant predictors of acceptance.

Key Words: Electric Vehicle, acceptance, mobility behavior, longitudinal survey

INTRODUCTION

In recent years, rising concerns about climate change have led to greater interest in energy efficient and low-carbon technologies. Investigations in the transportation sector play an important role, because traffic presents a major source of CO_2 emissions. In 2008, car traffic in Germany was responsible for 15.1% of total CO_2-emissions emphasizing the need for the development of alternative vehicular systems (*1*). The European Commission also stresses the need for change by setting requirements for car manufactures. For example, by 2015, the average fleet emission of newly registered cars must not exceed 130 g/km. Car manufactures could earn credits up to 7 g/km if they assemble their fleets with innovative concepts like electric vehicles (*2*).

This development sets the basis for the revival of electric vehicles (EVs). The history of EVs dates back to the late 19th century, but after their heyday around 1912, EVs fell into decline, occupying a niche product rather than a common means of transportation. Internal combustion engines (ICEs) have dominated the streets until today.

Apart from car manufactures that wish to fulfill EU requirements, German politicians recently promoted the development of EVs with the goal that 1 million electric cars should be placed on German roads by 2020 (*3*). To achieve this ambitious goal, the government has passed an initiative that supports investigations specifically concerned with EVs.

However, the challenge of promoting the adoption of greater EV use is related not only to technical feasibility, but also to acceptance of EVs in society. Without widespread acceptance of EVs, long-term goals, such as CO_2 reduction and independence from oil, will not be achieved unless other technologies are employed. The degree of novelty of EVs and how this factor could influence acceptance has been discussed by several researchers (*4*). Drivers encounter completely new concepts while using an electric vehicle compared to a conventional car. For example, charging procedures, recharge duration, cable handling as well as setting correct amperage, are only a few of the new aspects that determine the perceived challenge of EVs. Other characteristics that differ compared to ICEs include limited driving range per full charge cycle, very low noise, strong acceleration and

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limited space. Driving an EV poses different challenges that consumers need to be willing to deal with. To obtain greater insight into the potential market of EVs, two questions need to be evaluated:

- Is the actual state of development of EVs accepted by users/potential consumers?
- Does long-term experience with EVs change or influence attitudes?

If acceptance among EV drivers decreased considerably over time, the reputation of EVs would decline accordingly. In contrast, if positive experience effects are obtained, the probability of widespread acceptance of EVs could rise. Furthermore, scientific knowledge about personal factors that predict the level of acceptance is of great value regarding future market analysis. To investigate factors influencing acceptance, reliable instruments for measuring the construct are required. A long-term field trial is a promising basis for the development of an instrument that could also measure the impact of experience. In the interim, self-monitored mobility behavior could serve as an indicator for the validity of subjective acceptance data.

THEORY

Acceptance assessment

A lack of published research examining the acceptance of EVs is coupled with the problem of nonconforming variables currently in use for measuring acceptance. For the most part, attitudes (*5, 6, 7, 8*) and purchase intentions (*6, 7, 8, 9*) have been used as indicators for acceptance. Gärling and Johansson (*6*) and Gärling (*7*) found that participants were positive regarding safety, cost of maintenance, attractiveness, and usefulness for different purposes. Gould and Golob (*8*) used only one item, which stated that EVs "are a key solution to solving air pollution in California", and thus covered a totally different aspect of EV use. However, the above-mentioned items are probably all important for the measurement of attitude towards EVs.

A literature review on acceptance of alternative fuel vehicles provides a similar picture. Dinse (*10*) and Altmann and Graesel (*11*) measured acceptance using attitude items, such as risk perception of H_2 technology development, willingness to pay more for alternative fuel and environmental friendliness of H_2. Martin *et al.* (*12*) focused on vehicle performance and safety-related issues (e.g., refueling and driving a hydrogen vehicle). Furthermore, in another fuel cell vehicle study attitudes were measured by the degree of "support for the introduction of cleaner fuels and technologies in the taxi fleet" (p. 692, *13*).

A model of acceptance was developed by Schulte *et al.* (*14*). Although no data-based validation of the model was performed, it was published for measuring acceptance of hydrogen fuel usage in cars. The authors assume that three factors directly affect acceptance: perception of a product, individual values and needs of a person. In summary, the same issue that arises in the EV literature also occurs in alternative fuel vehicle research: By now there is no standard procedure to measure attitude towards EVs – and no clear definition of acceptance or standardized way to measure it.

In research on Advanced Driving Assistance Systems (ADASs), the measurement of acceptance is also a widely discussed topic. "Although it is recognized that acceptance, acceptability, and support are important, a clear definition of what acceptance and acceptability are and precisely how they should be measured is still absent" (*15*, p. 165). One of the widespread models is the Technology Acceptance Model (TAM, *16*) developed for information technology evaluation. It states that perceived usefulness and perceived ease of use determine usage intentions. Van der Laan *et al.* (*17*) designed a simple method which several authors used to evaluate ADASs (e.g., *18, 19*). It measures acceptance on two dimensions – Satisfaction and Usefulness – using nine semantic differentials.

The most prominent theoretical framework for acceptance measurement is the Theory of Planned Behavior (TPB, *20*). According to this theory, behavioral intentions are determined by the

person's evaluation of a certain behavior (*attitudes towards behavior*), the perception of beliefs in their social environment (*subjective norm*) and the perception of their own capabilities (*perceived behavioral control*). Although this model builds a stable foundation for acceptance measurement, it can be argued that more factors of influence, such as experience, gender, or personal traits, should be considered in acceptance research. The wide variety of methods available for acceptance measurement underlines this request. Based on regression analyses results, Arndt and Engeln (*21*) merged the TPB and other factors, such as individual characteristics, perceived product attributes, and willingness to pay, into a more complex model of acceptance regarding driver assistance systems. Although validation of this model is still missing, it is a first step towards an all-embracing model of acceptance for driving assistance systems that could be adapted to EV research.

In summary, research on ADASs offers a lot of knowledge that could be transferred to investigations of alternative fuel vehicles. The TPB provides a promising foundation for upcoming acceptance studies on EVs, but it is not as economic as, for example, the van der Laan Acceptance Scale (*17*). To evaluate the key issue of this paper, namely, experience effects, we focus on attitudinal acceptance assessed with customized attitude scales and the van der Laan Acceptance Scale (*17*).

Experience and Acceptance

As mentioned in the introduction, experience has a high impact on acceptance. Kurani *et al.* (*22*) discussed negative attitudes towards EVs among potential consumers and stated that a lack of information and experience causes uncertain results and incorrect assumptions in consumer research. A few studies (*6, 7, 8*) manipulated degree of experience. In an 11-week trial, EV users' attitudes did not change with increasing experience (*6, 7*). In contrast, Gould and Golob (*8*) conducted a 2-week field trial and reported that the judged environmental efficacy of the EV was higher at the end rather than the beginning of the study. In hydrogen vehicle research, higher exposure rates positively influenced evaluation of hydrogen vehicles in a ride-and-drive clinic (*12*) as well as in a 7-month field trial (*23*). Based on these findings, in the present study we hypothesized that users' attitudes would become more positive towards EVs if the EV was available in their daily routine for a longer period of time.

Other influencing factors

In addition to experience, several other factors are discussed in terms of influencing acceptance of EVs. One hypothesis, which describes the impact of an ICE vehicle in the household on the level of acceptance of EVs, is the Hybrid Household Hypothesis (*24, 25*). The authors argued that acceptance should be higher for households that own a combination of at least two cars, including a conventional car and an EV, compared to households in which an EV would be the only car. Kurani *et al.* (*24*) showed that people in potential hybrid households more often chose cars with a limited range than theoretically deduced.

Another relevant factor discussed in several previous studies is environmental concern. In many cases, this factor did not significantly influence acceptance of green transport (*11, 13,* in the short-term setting*; 22, 23, 25, 26*). However, some authors reported effects of environmental concerns, but other factors, such as price and performance, had a greater influence (*13*, in the long-term setting; *27, 28*).

In hydrogen vehicle research, Dinse (*10*) found that an individual's positive attitude towards technology has some impact on user evaluation. Furthermore, gender was reported to affect acceptance (*11, 27*).

In research on ADASs, reliability proved to be an important factor when analyzing acceptance (e.g., *29*). This can be expected to apply equally to acceptance research on EVs. Current EV technologies comprise a relatively new field among Original Equipment Manufacturers (OEMs). This in turn might cause customers to have concerns.

Based on a review of the literature, the objective of our study was to investigate the influence of the following factors on acceptance of EVs: gender, household type, experiences with electric or hybrid-electric drives, environmental concerns, and perceived reliability. Due to the selection process and the small number of female applicants it was not possible to equalize gender in the sample. Analyzing the impact of perception of vehicle attributes, for example, range, acoustics, and interface design, are beyond the scope of the present paper and will be the focus of future publications.

Attitudes and user behavior

Previous research has revealed that the majority of people are capable of using an EV in everyday life (e.g., *6*, 7, *30*, *31*). Against the background that "attitude is only one factor that affects behavior and the importance of attitudes varies over behaviors and situations" (p.6, *32*), it would be interesting to investigate if, and to what extent, attitude towards EVs influences user behavior. In this context, Gärling and Johansson (*6*) and Gärling (*7*) showed that stated attitudes towards EVs ranged between slightly negative and slightly positive and did not change during an 11-week study. Families took the EV for 64 % (*6*) and 55 % (*7*) of all trips and drove almost 40 % (*6*) and 35 % (*7*) of the total distance travelled by car with the EV during the study period. In Gärling's (*7*) study, after 9 weeks of EV use, about 90 % of participants stated that the EV fulfilled their travel needs. However, it is not known if variation in participants' usage intensity was reflected in their level of acceptance measured via questionnaires. Weinert *et al.* (*33*) compared attitudes and travel behavior of 751 bike and 460 e-bike divers. While both groups were equally satisfied with their bikes and showed similar trip purposes and frequencies, no within-group comparison was performed. In the case of EVs, within-group effects have not been investigated yet.

Present Research

This paper presents results from a long-term field study that starts prior to users' acquisition of EV experience and follows users as they gain more and more experience. Therefore, the study provides valid data on changes in attitudes and behavior. Long-term data collection during EV use supports the analysis of how usage behavior is linked to attitude and which of the various factors might be important.

STUDY DESIGN

Methods

The present paper contains data and results of a large-scale field study conducted in the metropolitan area of Berlin, Germany. The study, funded by the German federal government, is based on a cooperative project between the BMW Group, Munich, and Vattenfall Europe AG, Berlin, aimed at investigating the potential of EVs in megacities. The study is divided into two periods of 6 months in which 40 private users integrate an EV in their household routine. With the first period completed, the focus of this paper includes findings thus far. During the first study period three points of data collection took place. Participants answered questions before receiving their EV (T0), after 3 months of driving (T1), and when returning the EV after 6 months (T2). Of particular interest, through the application of repetitive measurements, changes in attitudes and behaviors may be observed.

In addition to data collected via structured interviews, questionnaires, travel and charging diaries, data were also gathered from the CAN-bus via data loggers within the vehicle. Data loggers continuously record several parameters, for example, mileage, speed, acceleration, braking and charging cycles. The usage of such a variety of methods provides valuable insights into potential advantages and disadvantages of EVs. The following section gives a detailed description of the methods implemented and data analyzed in the current research. Additional methods for related research questions are described in detail in Krems *et al*. (*34*) and in Cocron *et al.* (*35*).

Questionnaire

The first questionnaire comprised a total number of 129 items and was sent to users before receiving their EVs (T0). In sum, this survey mainly contained questions about users' expectations and attitudes. Subsequent questionnaires, which followed after 3 (T1, 306 items) and 6 months (T2, 355 items), aimed at collecting data about experiences and detecting time-based differences in users' experiences and acceptance of the EV. In this paper, results from items concerning acceptance will be reported.

In terms of acceptance measurement, seven items were generated specifically covering attitude towards electric vehicles. The first item, "Electric vehicles are a key solution to solving air pollution", was chosen following Gould and Golob's (*8*) acceptance measurement. A 6-point Likert Scale from 1 (completely disagree) to 6 (completely agree) was adopted for all attitude items. The remaining six items are:

- "Electric vehicles are the means of transport for the future."
- "I am not convinced of electric vehicles." (inverted)
- "Electric vehicles should play an important role in our mobility systems."
- "Electric vehicle use results in driving pleasure."
- "I think that as a sole vehicle, an electric vehicle is not suitable for a household." (inverted)
- "Electric vehicles are suitable for everyday use."

Additionally, a Single-item Measurement (*36*) was included to assess general acceptance level. The item fragment "would recommend to my best friend" is supposed to reliably predict customers' behavior in most branches (*37*), and was therefore used as an item for the Single-item Measurement. Furthermore, as a standard instrument for measuring attitudinal acceptance, the van der Laan Acceptance Scale (*17*) ranging from –2 to 2 was implemented. Users were asked to respond to the nine semantic differentials while evaluating the whole system "MINI E".

Together with acceptance, other topics were integrated in the questionnaires. Environmental concerns (*38*) and affinity for technological innovations (*Enthusiasm while using technologies*, *39*) were inquired. Additionally, one item was added to evaluate if EVs were perceived as reliable.

Travel diaries

Travel diaries are a well-established method applied in transportation research to obtain travel data, and have already been implemented by other EV researchers (*8*). Similar to other studies (*40*), participants logged their own daily trips by filling in these diaries for 1 week. To gain a satisfying picture of mobility patterns during each trip, travel diaries contained a number of parameters: Means of transportation, trip purpose, departure, and arrival times. Travel diaries were also administered three times during the study (i.e., T0, T1, T2). Before users received the EV, travel patterns with the conventional car were assessed to establish a baseline. After 3 months and at the end of the study, data on mobility behavior including use of the EV were collected.

Electric Vehicles

Selected users drove a standard MINI Cooper that was converted to a battery-powered vehicle served by a rechargeable lithium ion battery pack using 32 and 12 Amperes. The MINI E is a two-seater, has 150 kW power and 220 Nm of torque, and reaches a maximum speed of 152 km/h (94 miles/h). The EV's regenerative braking system transfers kinetic energy from the vehicle's momentum back into the battery. Whenever the driver releases the gas pedal, the regenerative braking system is engaged and causes deceleration. Public charging stations throughout Berlin were complemented by at-home "wallbox" units. An empty battery could be recharged in about 4 hours using a 32-Ampere fuse. A single charge afforded a range of 250 km (155 miles) under ideal conditions.

Participants

Study participants were recruited from the Berlin Metropolitan area. More than 700 people applied to join the 6-month period of EV use via an online application form. Potential users needed to fulfill certain criteria (e.g., live in the metropolitan area of Berlin, be willing to take part in scientific surveys, be willing to pay a monthly leasing rate, etc.). Out of the 161 applicants who successfully met these preconditions, the sample (N = 40) was selected based on two main criteria: Expected kilometers driven with the EV (< 250 km/155 miles vs. > 250 km/155 miles) and expected type of household (purely electric vs. hybrid; *24*, *25*). Due to the fact that only few applicants expected to fit the definition of a single-car household, the selected sample consisted of 31 expected hybrid and 9 expected purely electric vehicle households. Additionally, demographic variables were not comparable across groups, due to applicants' characteristics.

The selected sample was on average 48.1 (SD = 8.9) years old. It consisted of 33 male and 7 female users. Seventy-five percent of users held a university degree, 12.5 % had completed an apprenticeship, 7.5 % had finished vocational school, and 2.5 % counted graduation as their highest degree. Three quarters of users had not experienced an electric vehicle before. In 43 % of households, at least one child under 18 years lived in the family. During the 6 months of EV usage there were only two drop-outs.

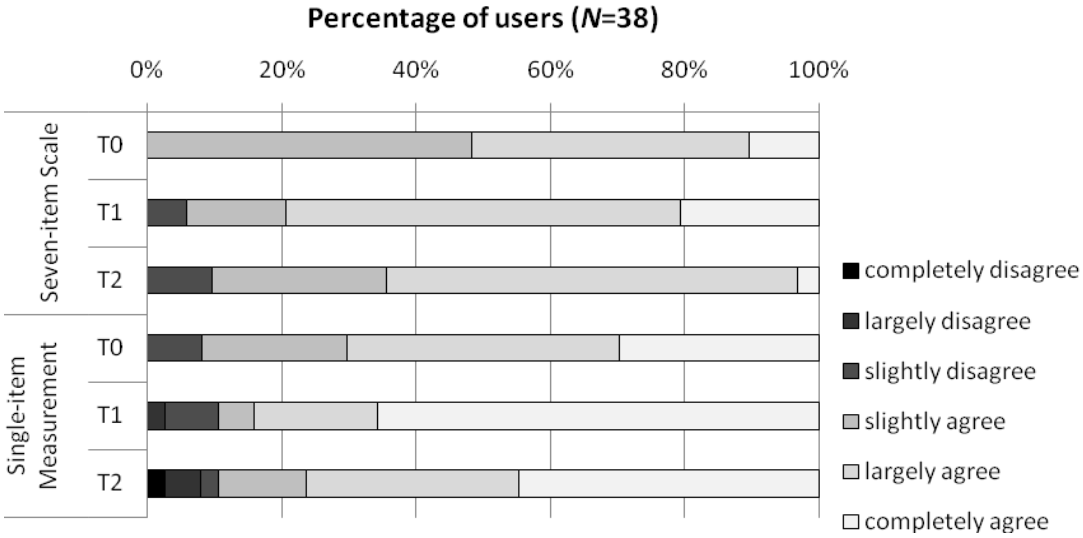
RESULTS

Attitude

Attitudinal acceptance of EVs was generally high at all points of data collection (Figure 1). Referring to the Seven-item Scale, acceptance was high at all times of measurements (T0: M = 4.62, SD = .71; T1: M = 4.91, SD = .74; T2: M = 4.57, SD = .70). There was also wide agreement concerning the question if users would recommend the MINI E to their best friend at all times during the project.

These findings reflect the results of the van der Laan Acceptance Scale (*17*), which showed that users judge the EV as satisfying (T1: M = 1.66, SD = .46; T2: M = 1.26, SD = .77) and useful (T1: M = 1.40, SD = .46; T2: M = 1.12, SD = .66). The different measures of acceptance were correlated for each point of measurement (Table 1); most correlations showed significance at a .05 level. Between the different times of data collection, reduced effects were observed, which point to change in acceptance possibly caused by an experience effect.

FIGURE 1 Levels of agreement for the Seven-item Scale and Single-item Measurement at three different points of data collection (T0, T1, T2).



Experience

After users had experienced the EV for 3 months, more people showed a largely or completely positive attitude towards EV (Figure 1). An ANOVA with repeated measurement led to a significant experience effect for the Seven-item Scale, $F(70, 2) = 6.24$, $p < .01$, $\eta^2_p = .15$. Attitude towards EVs before receiving the vehicle (T0: $M = 4.62$, $SD = .71$) was not as positive as shown after 3 months (T1: $M = 4.91$, $SD = .74$); this proved significant in post-hoc tests ($p<.05$). At the second point of data collection, acceptance decreased (T1: $M = 4.57$, $SD = .70$, $p < .01$). Then, it returned to a level similar to the beginning, so that acceptance measured at T0 and T2 did not differ significantly ($p = 1.00$). A similar picture emerged when analyzing the experience effect on Single-item Measurement, $F(72, 2) = 3.36$, $p < .01$, $\eta^2_p = .09$. In the beginning of the study, mean approval was 4.92 ($SD = .92$), rose to 5.38 ($SD = 1.09$) after 3 months and then dropped to 4.97 ($SD = 1.23$) after 6 months. The post-hoc test showed that mean acceptance was significantly higher after 3 months compared to the time before receiving the EV ($p < .05$). The difference between the second and third point of data collection was not significant ($p = .07$). However, the Seven-item Scale showed a significant decline in acceptance.

Analyzing the van der Laan Acceptance Scale (*17*) revealed analog findings. Acceptance of the MINI E was lower after 6 months compared to acceptance after 3 months. Satisfaction (*17*) decreased significantly, $t(37) = 3.38$, $p < .01$, from a mean value of 1.66 ($SD = .46$) to 1.26 ($SD = .77$) and Usefulness (*17*) changed from an average of 1.40 ($SD = .46$) to 1.12 ($SD = .66$), $t(37) = 2.68$, $p < .05$.

Other influencing factors

A multiple regression was calculated to investigate the impact of previous experience with electric drives, environmental concerns, affinity towards technology, and perceived reliability of EVs. To this end, a Seven-item Scale was chosen as acceptance measurement because it could be implemented at three points of data collection and correlated more highly with Satisfaction and Usefulness compared with the Single-item Measurement (Table 1). In addition, the Seven-item Scale evaluates the attitude towards EVs in a broader sense than the van der Laan Acceptance Scale (*17*). Therefore, results of the second point of measurement will be focused upon here. That is, attitude ratings are based on a more developed picture of EVs – the EVs are no longer a completely new product to users (*4*). The "inexperienced" acceptance values are included in the analysis to test if they reliably predict "more experienced" acceptance. No data from T2 were included, since additional, uncontrolled factors like winter conditions came into play. In the multiple linear regression analyses two factors turned out to be significant predictors of EV acceptance after 3 months of driving (Table 2). Environmentally conscious participants, $\beta = .60$, $t(30) = 5.00$, $p < .01$, and participants with a higher level of acceptance before receiving an EV, $\beta = .40$, $t(30) = 3.32$, $p < .01$, had higher acceptance values after 3 months of experience. The model explained 59 %, $F(4, 30)=10.91$, $p < .01$, of the variance of the acceptance data at the second point of data collection.

Travel behavior

A question of interest is the extent to which participants drive their EVs compared to previous means of mobility. EV usage in relation to all means of transportation and to ICE use was analyzed three times, 1 week for each data collection. Four variables were relevant for the analyses: Trip frequency using the EV relative to all trips and all car trips, as well as percentage of kilometers driven with the EV compared to entire mileage travelled (EMT) and vehicle mileage travelled (VMT). Due to a lack of quality data and low response rates at the last point of measurement, data of only 34 participants could be used for the description of travel behavior after 3 months. After 6 months, 26 travel diaries were analyzable; 25 of these were comparable to midterm diaries. With the aim to compare the percentage of trip frequency and trip mileage using an EV between the two points of measurement, calculations based on the 25 comparable cases were made.

TABLE 1 Correlations between different scales of acceptance measurement before receiving an EV, after 3 months, and after 6 months of driving

			T0		T1				T2			
			1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
T0	1.	Seven-item Scale	–									
	2.	Single-item Measurement	.63** (37)	–								
T1	3.	Seven-item Scale	.65** (37)	.39* (36)	–							
	4.	Single-item Measurement	.23. (38)	.45** (37)	.46** (37)	–						
	5.	Satisfaction (*17*)	.15 (38)	.06 (37)	.53** (38)	.49** (38)	–					
	6.	Usefulness (*17*)	.39* (38)	.22 (37)	.66** (38)	.37* (38)	.65** (38)	–				
T2	7.	Seven-item Scale	.53** (37)	.44** (36)	.67** (36)	.35* (36)	.33* (37)	.42* (37)	–			
	8.	Single-item Measurement	.16 (38)	.23 (37)	.35* (37)	.61** (38)	.71** (38)	.48** (38)	.47** (37)	–		
	9.	Satisfation (*17*)	.38* (38)	.38* (37)	.33* (37)	.39* (38)	.40* (38)	.22 (38)	.64** (37)	.52** (38)	–	
	10.	Usefulness (*17*)	.45** (38)	.43** (37)	.46** (38)	.32* (38)	.42** (38)	.35* (38)	.70** (37)	.57** (38)	.89** (38)	–

Comments. T0 = before receiving EV, T1 = after 3 months, T2 = after 6 months of driving, correlations according to Pearson, (n) = number of included cases; * $p < .05$, ** $p < .01$, gray areas are represent correlations between the same scale at different points of measurement.

TABLE 2 Results of regression analysis

	b	***SE b***	***β***
Constant	.735	.841	
Seven-item Scale (T0)	.603	.121	.588**
Affinity towards technology (“Enthusiasm while using technologies”)	–.045	.065	–.083
Environmental concerns	.251	.075	.398**
Perceived reliability of EV	.068	.089	.090

Comments. **$p < .01$

After 3 months of driving, users took their EV on an average of 71 % (*SD* = 25) of all trips. Three months later, usage frequency did not differ significantly, as participants still used the EV for 70 % (*SD* = 35) of all trips. If EV usage relates only to vehicle use, percentages are even higher. In midterm travel diaries, participants logged 80 % (*SD* = 22) of their vehicle trips as EV trips and at the end of the study, still marked 77 % (*SD* = 26) as EV trips. This difference is also not significant.

If kilometers covered by all means of transportation are taken into account, the percentage of EV kilometers after 3 months in the study measured on average 65 % (*SD* = 33). This number decreased to 62 % (*SD* = 33) by the end of the study, but this difference was not statistically significant. Regarding the kilometers driven in 1 week, EV kilometers were also stable over time and accounted on average for 72 % (*SD* = 31) of aggregated kilometers at the midterm survey and 71 % (*SD* = 33) after 6 months.

Attitude and Travel behavior

Values on the attitude scales, frequency of trips and kilometers driven with the EV are relatively high. However, there are no significant correlations between the Seven-item Scale, Satisfaction, Usefulness and variables of mobility behavior. This might be due to the small variance in the acceptance scales. However, the Single-item Measurement is significantly linked to the percentage of trips driven with the EV in relation to the total number of trips ($r = .43$, $p < .05$) and to the vehicle trips ($r = .54$, $p < .01$) after 3 months of driving an EV. The correlations are in the range of medium to strong, but 6 months later they were not found again, where percentage of total number of trips: $r = .12$, $p = .531$; and percentage of total vehicle trips: $r = .171$, $p = .404$.

DISCUSSION

In the present study a wide variety of methods were implemented to investigate acceptance of EVs and suitability for everyday life. Both of these preconditions have to be fulfilled if EVs are to be launched on a larger scale. A key strength of this study is that users had the opportunity to experience an EV in their routine environment for 6 months, thus experiencing almost all potential advantages and disadvantages of EVs. A limitation of the present study, however, is that the sample might not be representative of the German population due to self-selection processes, conditions of the project (e.g., ownership of a parking space as selection criteria), and other factors (e.g., income, education).

Acceptance and influencing factors

Focusing on different attitude assessments provided interesting results on acceptance of the actual technological state of EVs. At all times of data collection, participants reported high values on all acceptance scales. Although acceptance levels differed during the usage period to a small extent, values were never less than 60 % of all available points and were at least as high as in the beginning of the project. Against this background it appears that EVs in their current technological state already meet the expectations of users and satisfy their transportation needs in everyday life. However, environmental and technological attitudes and user knowledge have to be kept in mind, when generalizing results.

The first 3 months of driving an EV positively influenced acceptance ratings, which is consistent with findings of previous research (*8*, *11*, *12*, *23*). However, results in the present paper differ from Gärling and Johansson's (*6*) report of a similar length study, where acceptance did not differ during the 11-week trial and remained low. Acceptance decreased in the second half of the usage period, which may have been due to winter conditions and was comparable to participants' ratings at the beginning of the study. Wintertime poses challenges for users, such as longer charging duration (e.g. *6*), and might therefore influence acceptance. In Gärling and Johansson's (*6*) field trial users also experienced wintertime, which could have led to the unchangeable low acceptance levels. However, in the present study attitude remained positive and led to the assumption that EVs are also suitable for the cold season.

Regarding other influencing factors, environmental concerns and earlier acceptance values proved to be valuable predictors of acceptance after 3 months of experience. The impact of environmental concerns again supports findings from other studies (*13*, in long-term setting; *27, 28).* Attribute studies as processed by Shaheen *et al.* (*23*) have not found an influence of strongly positive attitude towards the environment. However, in Shaheen's study (*23*) environmental concerns were

evaluated by statements concerning perceived importance of environmental topics and willingness of participants to change their behavior for environmental reasons. The items used to measure environmental concerns in this study were based on a more general perspective.

Mobility behavior and acceptance

Participants' travel needs seemed to be mostly satisfied by the EV. The percentage of EV trips and associated mileage covered was higher than in previous studies: Participants of the present study used the EV for 77 % of vehicle trips, compared to 64 % and 55 % in other studies (*6, 7*), respectively. The differences are even higher for the percentage of kilometers driven. The present sample covered from 71 % to 72 % of total vehicle mileage with the EV, whereas the Swedish sample covered a total of 39 % (*6*) and 35 % (*7*). The differences in mobility behavior indicate that the present sample seems to not only have a higher level of attitudinal acceptance, but also showed higher usage frequencies.

However, usage intensity and acceptance measured via questionnaires hardly showed any correlations. Either the attitude data did not include enough variance to produce a correlation with mobility behavior or too many other variables influenced the relationship between attitude and behavior.

CONCLUSION

The objective of this study was to examine methods for the investigation of EV acceptance. Although, there were almost no significant correlations with self-monitored behavior, all reported scales (e.g., Seven-item Scale, van der Laan Acceptance Scale *(17)*) correlated highly with each other. Thus, each scale seems to be reliable for the assessment of acceptance relating to attitudes. The aim of this study was to test if the current state of development of EVs is accepted and if EVs are suitable for peoples' daily routines. The sample investigated in the Berlin study showed a high acceptance of EVs. Although the sample was pre-selected and thus may not be representative of the German population, indicators, such as the percentage of trips and kilometers covered with the EV, clearly show that EVs are suitable for most daily trips in urban traffic. The results suggest that EVs have great potential to achieve widespread acceptance and thus have a considerable stake in our future mobility systems.

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REFERENCES

1. *Nationaler Entwicklungsplan Elektromobilität der Bundesregierung*. Berlin, August 2009, http://www.bmvbs.de/Anlage/original_1091800/...-Elektromobilitaet.pdf. Accessed July 25, 2010.
2. European Parliament and Council of the European Union. Regulation (EC) No 443/2009 of the European Parliament and the of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the communities' integrated approach to reduce CO_2 emissions from light-duty vehicles. *Official Journal of the European Union*, L 140, 2009, pp. 1–15.
3. *National Inventory Report for the German Greenhouse Gas Inventory 1990 – 2008.* Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2010, Climate Change 04/2010, Umweltbundesamt, Dessau-Rosslau, http://www.umweltbundesamt.de/uba-info-medien-e/mysql_medien.php?anfrage=Kennummer&Suchwort=3958. July 25, 2010.

4. Urban, G. L., B. D. Weinberg, and J. R. Hauser. Premarket forecasting of really-new products. *Journal of Marketing* Vol. 60, No.1, January 1996, pp.47–60.
5. Beggs, S. D., N.S. Cardell, and J. Hausman. Assessing the potential demand for electric cars. *Journal of Econometrics*, 16, 1981, pp. 1–19.
6. Gärling, A., and A. Johansson. *An EV in the family.* Paper presented at the 2nd KFB-Research Conference, Lund. June 1999.
7. Gärling, A. *Paving the way for the electric vehicle (Final Report)*. VINNOVA, Sweden, 2001.
8. Gould, J., and T.F. Golob. Clean air forever? A longitudinal analysis of opinions about air pollution and electric vehicles. *Transportation Research - D: Transport and the Environment*, Vol. 3, 1998, pp. 157–169.
9. Chéron, E., and M. Zins. Electric vehicle purchase intentions: the concern over battery charge duration. *Transportation Research Part A*, Vol. 31, Nr. 3, 1997, pp. 235–243.
10. Dinse G. *Akzeptanz von wasserstoffbetriebenen Fahrzeugen-Eine Studie über die Verwendung eines neuen und ungewohnten Kraftstoffs*. Institut für Mobilitätsforschung (ifmo-Studien), BMW AG, Berlin, 2001.
11. Altmann M, and C. Graesel. The acceptance of hydrogen technologies. *Report for the HyWeb*. LBST, Germany, 1998.
12. Martin, E., S. A. Shaheen, T. E. Lipman, and J. R. Lidicker. Behavioral response to hydrogen fuel cell vehicles and refueling: Results of California drive clinics. *International Journal of Hydrogen Energy*, 34, 2009, pp. 8670-8680.
13. Mourato S, B. Saynor, and D. Hart. Greening London's black cabs: a study of driver's preferences for fuel cell taxis. *Energy Policy*, Vol. 32, No. 5, 2004, pp. 685–95.
14. Schulte I, D. Hart, and R. Van der Vorst. Issues affecting the acceptance of hydrogen fuel. *International Journal Hydrogen Energy*, Vol. 27, No. 7, 2004, pp. 677–85.
15. Vlassenroot, S., K. Brookhuis, V. Marchau, and F. Witlox. Towards defining a unified concept of acceptability of Intelligent Transport Systems (ITS): A conceptual analysis based on the case of Intelligent Speed Adaptation (ISA). *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 13, No. 3, 2010, pp. 164–176.
16. Davis, F. D. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, Vol. 13, No. 3, 1989, pp. 319–340.
17. Van der Laan, J. D., A. Heino, and D. De Waard. A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C*, Vol. 5, 1997, pp. 1–10.
18. Biding, T., and G. Lind. *Intelligent speed adaptation (ISA), Results of large-scale trials in Borlänge, Lidköping, Lund and Umea during the period 1999–2002*. Publication 2002:89 E, Vägverket, Borlange, 2002.
19. Vlassenroot, S., S. Broekx, J. D. Mol, L. I. Panis, T. Brijs, and G. Wets. Driving with intelligent speed adaptation: Final results of the Belgian ISA-trial. *Transportation Research Part A: Policy and Practice*, Vol. 41, No. 3, 2007, pp. 267–279.
20. Ajzen, I. The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*, Vo. 50, No. 2, 1991. pp. 179–211.
21. Arndt, S., and A. Engeln. Prädiktoren der Akzeptanz von Fahrerassistenzsystemen. In: J. Schade, and A. Engeln (Eds.). *Fortschritte der Verkehrspsychologie* (pp. 313–337). VS Research, Heidelberg, 2008.
22. Kurani, K. S., D. Sperling, T. Lipman, D. Stanger, T. Turrentine, and A. Stein. Household Markets for Neighborhood Electric Vehicles in California. *Institute of Transportation Studies*, UC Davis, 1995. http://www.escholarship.org/uc/item/13v2w7x0. Accessed July 25, 2010.
23. Shaheen, S. A., E. Martin, and T. E. Lipman. Dynamics in behavioral response to fuel-cell vehicle fleet and hydrogen fueling infrastructure. In *Transportation Research Record: Journal of*

Transportation Research Board, No. 2058, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 155–162.
24. Kurani, K. S., T. Turrentine, and D. Sperling. Testing electric vehicle demand in 'Hybrid Housholds' usinga reflexive survey. *Transportation Research – Part D: Transport and Environment*, Vol. 1, No. 2, 1996, pp. 131–150.
25. Turrentine, T., and K. Kurani. *The Household Market for Electric Vehicles: Testing the Hybrid Household Hypothesis - A Reflexively Designed Survey of New-car-buying, Multivehicle California Households*. Institute of Transportation Studies, UC Davis, 1995.
26. Calfee, J. E. Estimating the demand for electric automobiles using fully disaggregated probabilistic choice analysis. *Transportation Research B*, Vol. 19B, 1981, pp. 287–302.
27. Chiu, Y. C and G. H. Tzeng. The market acceptance of electric motorcycles in Taiwan experience through a stated preference analysis. *Transportation Research Part D*, Vol. 4, 1999, pp. 127–46.
28. Sperling, D., W. Setiawan, and D. Hungerford. The Target Market for Methanol Fuel. *Institute of Transportation Studies*, UC Davis, 1995. http://www.escholarship.org/uc/item/18r3w4jb. July 25, 2010.
29. Adell, E. *Driver experience and acceptance of driver support systems – a case of speed adaptation*. (Doctoral dissertation). Thesis, Lund University, 2009, http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=1504012&fileOId=1511414. Accessed July 27, 2010.
30. Greene, Estimating daily vehicle distributions and the implications for limited-range vehicles, *Transportation Research B*, Vol. 19B**,** 1985, pp. 347–358.
31. Hautzinger, H. Verkehrsentwicklung und Einsatzpotential von Elektrofahrzeugen. In *VDI Berichte 985, Verein deutscher Ingenieure, VDI-Gesellschaft Energietechnik, Elektrostrassenfahrzeuge, Tagung Dresden, 20. und 21. Oktober 1992*. VDI Verlag, Dresden, 1992, pp. 17–34.
32. Aberg, L. *The role of attitudes in transportation studies*. Uppsala University, Uppsala, 2003, http://www.lth.se/fileadmin/tft/dok/KFBkonf/6Aaberg.PDF. Accessed Jan. 3, 2010.
33. Weinert, J. X., C. Ma, X. Yang, and C. R. Cherry. Electric two-wheelers in China: Effect on travel behavior, mode shift, and user safety perception in a medium-sized city. In *Transportation Research Record: Journal of Transportation Research Board*, No. 2038, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 62–68.
34. Krems, J. F., T. Franke, I. Neumann, and P. Cocron. Research methods to assess the acceptance of EVs - experiences from an EV user study. In T. Gessner (Ed.), *Smart Systems Integration: 4th European Conference & Exhibition on Integration Issues of Miniaturized Systems - MEMS, MOEMS, ICs and Electronic Components*. Como, Italy. CD ROM: VDE, 2010.
35. Cocron, P., F. Bühler, I. Neumann, T. Franke, and J. F. Krems. Methods to assess the acceptance of electric vehicles, submitted August 2010.
36. Wanous, J. P., A.E. Reichers and M.J. Hudy, Overall job satisfaction: how good are single-item measures? *Journal of Applied Psychology*, Vol. 82, No. 2, 1997, pp. 247–252.
37. Reichheld, F. F. The one number you need to grow. *Harvard Business Review*, Vol. 81, No. 12, 2003, pp. 46–54.
38. Oreg, S., and T. Katz-Gerro, T. Predicting proenvironmental behavior cross-nationally: Values, the Theory of Planned Behavior, and Value-Belief-Norm Theory. *Environment & Behavior*, Vol. 38, No. 4, 2006, pp. 462–483.
39. Karrer, K., C. Glaser, C. Clemens und C. Bruder. Technikaffinität erfassen – der Fragebogen TA-EG. In A. Lichtenstein, C. Stößel and C. Clemens (Eds.), *Der Mensch im Mittelpunkt technischer Systeme. 8. Berliner Werkstatt Mensch-Maschine-Systeme* (ZMMS Spektrum, Reihe 22, Nr. 29, S. 196–201). VDI Verlag GmbH, Düsseldorf, 2009.
40. Kunert, U., and R. Follmer. Methodological advances in national travel surveys: Mobility in Germany 2002. *Transport Reviews*, Vol. 25, No. 4, 2005, pp. 415–431.