Transportation Research Part F 21 (2013) 75–89

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

# Understanding charging behaviour of electric vehicle users

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ARTICLE INFO

*Article history:*
Received 23 October 2012
Received in revised form 19 April 2013
Accepted 3 September 2013

*Keywords:*
Electric vehicles
Charging
User behaviour
Field study

ABSTRACT

We examined the psychological dynamics underlying charging behaviour of electric vehicle (EV) users. Data from 79 EV users were assessed in a 6-month EV field study. On average, users charged their EV three times per week, drove 38 km per day, and they typically had a large surplus of energy remaining upon recharging. Based on first findings concerning charging style among mobile phone users, we hypothesized that user–battery interaction style (UBIS) is a relevant variable for understanding charging behaviour of EV users. We developed measures to assess UBIS. Results show that it is a relatively temporally stable characteristic which also shows some cross-device consistency. As predicted by our conceptual model, UBIS and comfortable range explain the charge level at which people typically recharged. UBIS was related to users' confidence in their mental model of range dynamics, the utilization of range, and to excess energy from renewable sources. This research has implications for optimizing sustainability of electric mobility systems.



## 1. Introduction

EVs are a promising form of sustainable[1] transportation because of their potential to reduce $CO_2$ emissions and air pollution (Holdway, Williams, Inderwildi, & King, 2010), mitigate risks associated with peak oil (Hirsch, Bezdek, & Wendling, 2005), and utilize excess energy from renewable sources like wind (Sundström & Binding, 2010). However, these effects are dependent on how an electric mobility system (EMS) is set up as well as how it is used (Eggers & Eggers, 2011; Franke, Bühler, Cocron, Neumann, & Krems, 2012). Therefore, the user is a critical parameter in the equation specifying the net environmental and economic benefit of an EMS.

Research has shown that it is challenging for users to utilize an EMS in an optimal way. For example, regarding the efficient use of limited energy resources, users have been found to maintain substantial psychological safety buffers in their range utilization (Caroll, 2010; Franke & Krems, 2013; Franke, Neumann, Bühler, Cocron, & Krems, 2012). This inefficient utilization of precious range resources has an adverse impact on the ecological and economic sustainability of EMS, because battery size is linked to ecological footprint (Hawkins, Gausen, & Strømman, 2012; McManus, 2012) and the affordability (i.e., chance for broad adoption) of EVs (Neubauer, Brooker, & Wood, 2012; Thomas, 2009). Thus, it would be beneficial to avoid wasting substantial shares of usable battery capacity as psychological safety buffer, but how can EV users be supported in the efficient utilization of energy resources?

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[1] With the term sustainability we refer to the "three pillars" model of sustainable development (UN General Assembly, 2005) covering environmental, economic and social facets of sustainability. In particular, EVs must be beneficial for environmental protection and economic development to be considered a sustainable technology. This especially refers to the efficient use of energy and resources.

1369-8478/$ - see front matter 
http://dx.doi.org/10.1016/j.trf.2013.09.002

Findings show that some users adopt more efficient usage patterns than others and certain psychological variables have been found to be related to those individual differences (Franke & Krems, 2013; Franke, Bühler, et al., 2012; Franke, Neumann, et al., 2012). These variables may help to inform the development of strategies promoting more sustainable utilization of an EMS. It is therefore important to understand variables underlying individual differences in EMS users' utilization of energy resources, both, in terms of depletion (e.g., trip decisions) and replenishment (e.g., charging decisions) of resources. Previous research in this area has largely focused on the former facet, depletion of resources (Franke & Krems, 2013; Franke, Neumann, et al., 2012). The present research aims to better understand the psychological dynamics underlying replenishment of resources (i.e., charging decisions).

To this end, a field trial approach was applied in which 79 participants leased an EV for 6 months and provided subjective and objective data. In order to advance the adaptive control of range resources framework (Franke & Krems, 2013; Franke, Neumann, et al., 2012), we applied concepts developed through preliminary research on mobile phone users charging style (Rahmati & Zhong, 2009) to the field of electric mobility. We developed measures to assess participants' charging-related user–battery interaction style (UBIS) and analyzed characteristics of UBIS, accordingly. We then examined if UBIS is associated with certain charging patterns. In addition, we examined whether UBIS and comfortable range can account for variance in charging behaviour, and whether there is an association between UBIS and users' confidence in their mental model of range dynamics. Finally, we analyzed the relationship between UBIS and efficient usage of the EMS, with a focus on range utilization and the efficiency of utilizing excess energy from wind.

### 1.1. Interacting with limited energy resources

To better understand the efficient use of energy (i.e., mobility) resources, we have developed a conceptual model (Franke & Krems, 2013; Franke, Neumann, et al., 2012), based on principles of self-regulation and control theory (Carver & Scheier, 1998; Fuller, 2011). Our model is similar to the transactional model of stress (Lazarus & Folkman, 1984) in that it proposes a highly subjective appraisal of range resources and a high variance in coping strategies. Indeed, in previous research, we found substantial variance in users' appraisal of objectively similar range resource situations (Franke & Krems, 2013; Franke, Neumann, et al., 2012) and identified several stress-buffering variables similar to those Lazarus and Folkman (1984) proposed (e.g., internal control beliefs). Rather than focusing on users' individual *appraisal* of available range resources, the present study focuses on individual differences in *coping style* related to charging. Fig. 1 depicts the model from the perspective of a single charging decision (i.e., the control loop of user–battery interaction).

The model is based on the premise that whenever users interact with limited energy resources, they continuously monitor and manage the relation between their mobility needs (e.g., distance of next trip) and their mobility resources (e.g., remaining range). This ratio (i.e., the perceived available range buffer) is then compared to the user's preferred range buffer (i.e., the user's comfortable range) which has been shown to vary considerably between users (Franke & Krems, 2013; Franke, Neumann, et al., 2012). The range appraisal (the experienced discrepancy between available and preferred range resource buffers) leads to a certain degree of range stress (i.e., range anxiety). The more range stress, the more likely the user will apply coping strategies (e.g., drive more economically, charge the car) to resolve the situation. Consequently, the users' comfortable range plays a key role in predicting the likelihood that a user will apply coping strategies (e.g., charging) in a given situation.

Although appraisal of a range situation is an important determinant of users' coping behaviour, we do not assume that this is the only determining factor; rather, we posit that users adopt a preferred coping style when dealing with limited energy resources which we call user–battery interaction style (UBIS). This is based on the observation, that although EV energy resources are limited, experience of subjectively critical range situations is still relatively infrequent (Franke & Krems, 2013;

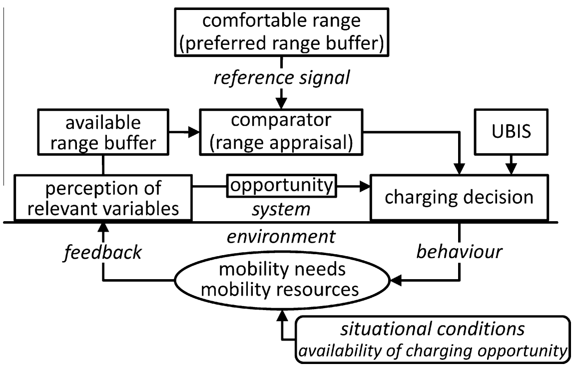


**Fig. 1.** A charging decision according to the adaptive control of range resources model (i.e., the control loop of UBI). The likelihood of charging increases as the salience of a critical remaining range situation increases (available ⩽ comfortable range). Users with a lower UBIS will, however, tend to avoid such situations by charging more often than necessary and therefore, they will tend to base their decision on contextual triggers (i.e., the opportunity to charge). In contrast, users with a higher UBIS will tend to base their decision on range resources (i.e., the experienced necessity to charge). Hence, comfortable range affects the control process at an earlier stage (appraisal) while UBIS affects the control process at a later stage (decision on coping behaviour).