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Original research article

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 CO_2 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.

1. Introduction

About 22% of the CO_2 emissions in Europe are caused by transportation systems [1]. Furthermore, other harmful environmental impacts like air pollution intensify in specific areas, for example due to increasing urbanization [2]. 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., [3]). 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., [4]).

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., [5]). However, there are also several consumer concerns, such as long charging time, high purchase costs and limited range (e.g., [5,6]). In fact, limited range is regarded as one of the main disadvantages of BEVs (e.g., [5,7]).

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 a plug-in hybrid EV design). 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 [8]. 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., [5,9,10], there is very little research on the perception and acceptance of EREVs. The present study investigates consumer

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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., [8,11]). 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 [12]. 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 [13].

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 [14]. 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 [15].

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 [16], 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., [8]) 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., [17]), the longest daily driving distance per week or per year (e.g., [18,19]) or the share of daily mobility needs in one year that can be met by a typical EV range (e.g., [20]). 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., [10,21]). 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., [5,7,22]), intention to purchase, recommend or adopt (e.g., [5,10,22,23]) or willingness to pay (e.g., [5]) 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:
  - (Q1.1) How are EREVs generally *appreciated* relative to BEVs?
  - (Q1.2) How are EREVs *valuated* relative to BEVs?
- (Q2) Do the theorized factors predict individual differences in acceptance of EREVs versus BEVs? Specifically: