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ORIGINAL ARTICLE

New opportunities for electric car adoption: the case of range myths, new forms of subsidies, and social norms

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Introduction

Transport sector challenges and electric car adoption in Germany

CO_2 emissions from global transport are growing steadily and contribute 23% of energy-related CO_2 emissions today (Sims et al. 2014). The transport sector will face major challenges in the future due to climate change mitigation and the international goal of deep decarbonization (Creutzig et al. 2015). Electric cars[1] provide an opportunity to increase energy efficiency in road transport, as they can contribute significantly to emission reductions when combined with renewable electricity sources (Hawkins et al. 2013). Furthermore, a shift from combustion engine cars to electric cars would increase independence from fossil fuels and reduce pollution and noise on the local level (Van Wee et al. 2012). To tap the full potential of electric cars, they should not only substitute combustion engine cars, but be thoughtfully incorporated into sustainable concepts for the whole transport sector (Schwedes et al. 2013). These concepts should offer solutions for problems caused by car traffic in general, including questions of land use, health impacts, traffic safety, and social fairness (Gössling 2016; Manville and Shoup 2005; Martens 2006; Van Wee 2014).

In Germany, traveling by car is the most popular way to get from A to B. Seventy-seven percent of German households own a car and 70% of the population uses a car on a regular basis (i.e., daily or multiple times a week; Benthin and Gellrich 2017; Destatis 2016). Although public transport and non-motorized individual travel modes have become increasingly important in recent years, further increases in car travel are expected over the next decade (Bundesministerium für Verkehr und digitale Infrastruktur 2016; Infas and DLR 2010). Most car owners like to drive: 86% report that they enjoy driving and 32% report that this enjoyment is one of the top three reasons why they own a car (DAT 2016). Perceived car dependency is high among drivers: 90% report that their current level of mobility would decline if they gave up their car (DAT 2016). The use of alternative forms of transport depends on the regional context. In cities with more than 100,000 inhabitants, 33% of the population uses public transport regularly, but only 14% of residents of smaller cities and rural areas do so (Benthin and Gellrich 2017). This is most likely caused by infrastructural factors and fewer alternative travel modes in areas outside of larger cities. For longer journeys (more than 250 km), cars are the most

[1] With the term *electric car*, we mean a car that is powered solely by a battery.

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frequently used travel mode in the German population (58%), followed by the train (20%; Infas and DLR 2010). As a result, action on all levels will be necessary to finally achieve considerable reductions of CO_2 emissions in the transport sector and a more sustainable transport system in general (e.g., Bracher et al. 2014).

In 2011, the German government set the ambitious goal of one million electrified cars on German streets by 2020. However, adoption rates have been disappointingly low: In January 2016, only 25,502 electric cars were registered (KBA 2016).[2] The government sought to reduce CO_2 emissions while also securing the international competitiveness of the well-established German car industry (Bundesregierung 2011). Thus, the support scheme for electric cars relied mainly on funding for research and development until recently. In reaction to the low sales figures, the government broadened its support scheme for electric cars in June 2016. Under the new law, electric car buyers receive a €4000 grant, half of which is financed by the government and the other half by the German car industry. Nevertheless, electric car sales figures did not pick up significantly in the months following the introduction of the grant (BAFA 2016).

The need for psychological research

These low sales figures are somewhat surprising when we consider that a large share of the German population sees electric cars as environmentally friendly and as the vehicle of the future (Rückert-John et al. 2013). Nevertheless, in the present, people report that the high purchase price and limited range of electric cars combined with a weakly developed public charging infrastructure represent major barriers (e.g., CreditPlus Bank 2016). With public debate also dominated by these considerations, contributions from the field of psychology are often overlooked (Barth et al. 2016; Bobeth and Matthies 2016). Such contributions come from models of intentional decision making such as the *theory of planned behavior* (Ajzen 1991) as well as models integrating the theory of planned behavior with variables from other models like the *comprehensive action determination model* (Klöckner 2013). They suggest that it is not only attitudinal factors (e.g., economic reasoning) and contextual factors (e.g., electric cars' current range and charging infrastructure) that play an important role, so do factors like social influence and people's moral beliefs. The *diffusion of innovations theory* (Rogers 2003) assumes that non-rational aspects like status or risk affinity are especially important in the early diffusion stages of a new technology. Adopters in these stages strive to maintain their status as experts on new technologies within their social environment. As we can presume that many factors interact in determining a household's decision of whether or not to buy an electric car, psychological studies can offer the more comprehensive view that is needed to understand why sales figures are still low (Rezvani et al. 2015).

In the following paper, we investigate households' adoption of electric cars from a psychological point of view. Our goal is to learn more about hitherto neglected psychological mechanisms behind households' adoption of electric cars as an energy-efficient technology and develop recommendations for policymakers. Thus, in addition to theoretical questions, our research was driven by a practical one: How can electric cars' diffusion process be accelerated by policymakers?

Theoretical background

Electric car adoption research: current state

Since the new generation of electric cars was introduced to the market around the year 2010, a multitude of empirical studies on the factors behind households' electric car adoption have been carried out. These studies are mainly based on two kinds of surveys. The first kind consists of questionnaires conducted online, in paper-and-pencil format or via face-to-face interviews (e.g., Rezvani et al. 2015). In these studies, the dependent variable is mostly the intention to buy or use an electric car or interest in electric cars. Factors that might explain electric car adoption are investigated using correlative methods of data analysis. The second kind of survey relies on stated-preference methods, most often choice experiments (e.g., Dimitropoulos et al. 2013; Hoen and Koetse 2014). Those allow for simulated purchase decisions to be studied as dependent variables. Both kinds of studies rely on either convenience samples or samples of a certain group of interest to the

[2] The German government has not specified the targeted degree of electrification. We assume that *plug-in hybrid electric cars* (cars with two power trains, in most cases powered by a battery and a combustion engine) are also included in the goal. This would roughly double the number of sold cars to approximately 50,000 (Electrive.net 2016), still very low compared to the government's goal.

researchers in terms of sociodemographic aspects, such as potential early adopters or representative samples of the car buyer population in a region or a country.

We will now provide a brief overview of the factors that these studies have found to influence households' electric car adoption, assigning them to two categories. *Contextual characteristics* are factors that describe the situational circumstances of a purchase decision. They can concern the current electric car market, the current state of the technology, infrastructural aspects, or economic aspects. *User characteristics* describe the person or persons making the decision. They can concern sociodemographic aspects or personal attitudes, values, or norms.

In terms of contextual characteristics, one well-established finding is that the combination of current range limitations and a perceived lack of public charging infrastructure forms a barrier to adoption. Dimitropoulos et al. (2013) found that range limitations are a major barrier to adoption in their meta-analysis of international stated-preference studies on range perceptions. Lieven (2015) analyzed the effect of policy measures with a discrete choice experiment in 20 countries on five different continents. His results suggest that, given current range limitations, a well-developed public charging network is an essential precondition for electric car adoption. Another well-established finding is that costs play a major role in the purchase decision. To provide just a few examples, discrete choice experiments from Portugal (Oliveira et al. 2015) and the USA (Hidrue et al. 2011) underline the importance of cost aspects, particularly purchase price (negative effect) and fuel cost savings (positive effect). In addition, several psychological studies focus on other contextual aspects. Correlative studies from the UK (Schuitema et al. 2013) and the Netherlands (Noppers et al. 2014) suggest that symbolic aspects (e.g., status and identity) are just as important for car purchases as instrumental aspects (e.g., range and infrastructure). Two studies looked into the role of social norms: a survey study carried out in Germany found social norms to be at least as important as cost aspects (Barth et al. 2016), whereas choice experiment studies from the Netherlands found their importance to be much lower than that of other contextual aspects (Kim et al. 2014; Rasouli and Timmermans 2016). Thus, the role of social influences still needs to be clarified.

Regarding *user characteristics*, several sociodemographic factors seem to be correlated with greater willingness to adopt electric cars. In a survey study carried out in Germany (Peters and Dütschke 2014), being middle-aged, male, living in a multi-car household with children, and having a high education and income level were associated with a greater likelihood of electric car adoption. The latter shows that financial aspects are not only important as a contextual factor (e.g., comparing the purchase price of electric cars to that of combustion engine cars), but that the household's economic situation is also important for the purchase decision. Non-financial motives, including environmental concern, have been found to be influential as well. A cross-cultural survey study from Denmark, Belgium, and Italy (Barbarossa et al. 2015) and a survey study incorporating a stated choice experiment from the Netherlands (Bockarjova and Steg 2014) both suggest that environmental protection motives have a positive influence on electric car adoption. A survey study from Norway (Nayum et al. 2016) compared electric car buyers to other groups of car buyers, and found them to be similar on many psychological characteristics. However, differences were found in the awareness and acceptance of sustainability problems caused by car use (both of which were higher among electric car buyers). Another relevant motive is interest in technology as such. A survey study from the USA (Egbue and Long 2012) demonstrated that people with high technology enthusiasm are more willing to adopt electric cars, while a survey study in the UK (Morton et al. 2016) explored the influence of innovativeness, finding that adoptive innovativeness (i.e., peoples' adoption behavior of other innovative technologies) was positively related to electric car adoption.

A survey study from Norway (Klöckner 2014) that accompanied people interested in buying an electric car throughout their purchase decision process leads us to the assumption that different contextual aspects and personal motives might be relevant at different points of the process. In line with the theoretical model upon which the study was based (the *stage model of self-regulated behavioral change*; Bamberg 2013), Klöckner was able to demonstrate that people do indeed pass through different stages during the decision process in which different psychological concepts become important for shaping specific forms of intentions (e.g., in the earliest stage, personal, and social norms are important as they lead to the intention to make changes in one's own mobility behavior).

While the cited studies undoubtedly deepen our understanding of the topic at hand, the majority of them also suffer from at least two important limitations. First, either purchase decisions were not investigated at all (in most cases, purchase intentions were investigated instead) or the purchase decision was hypothetical. In almost, no cases were real-world purchase decisions studied. This is problematic because research has shown that intentions do not always directly translate into corresponding behavior (e.g., Bamberg and Möser 2007). Second, most samples consisted of people with no direct experience with electric cars or only brief experience. Inexperienced samples are problematic because people exhibit *psychological distance* towards new technologies, meaning that they think more abstractly and less concretely about them than about technologies they are familiar with (Liberman et al. 2007). Hypothetical assumptions about a distant technology may play a less important role or no role at all when the technology is more widespread and actual usage experience replaces those assumptions (Klöckner 2015). Only a very small number of studies have systematically sampled electric car owners (Barth et al. 2016; Nayum et al. 2016; Peters and Dütschke 2014). However, electric car owners in early diffusion stages might be highly motivated to buy an electric car, limiting the validity of findings based on such samples for the majority of the population (Rezvani et al. 2015).

Further support for some of these findings can be derived from research on household investment decisions related to other kinds of high-price technologies that were more widespread at the time of study. For example, Kastner and Matthies (2016) demonstrated the importance of costs, environmental concern, and social norms for investments in solar thermal energy in Germany. A qualitative interview study carried out in the USA (Heffner et al. 2007) and a quantitative survey study carried out in Australia (Chua et al. 2010) both demonstrated the relevance of social aspects for households' adoption of hybrid cars. These studies also suggest that environmental protection motives are not the main factor behind the purchase decision, as the most environmentally concerned people might prefer to abstain from driving altogether. To sum up, the studies cited in this section allow hypotheses to be drawn about which factors are important for electric car adoption. Nevertheless, there is still a lack of comprehensive and systematic research on the factors behind real-world decisions for or against purchasing an electric car.

Expanding the scope

The absence of studies with convincing samples of either experienced electric car users or people who are currently in the process of deciding whether or not to purchase an electric car is most likely caused by a simple practical problem: The current low diffusion rates of electric cars in the general population make such samples hard to recruit. A few studies have sampled people who tried electric cars for a limited time as part of field trials. Survey studies conducted before and after 3-month trial tests in Denmark (Jensen et al. 2013) and Germany (Franke and Krems 2013) indicate that hands-on usage experience is a crucial factor for people's perceptions of electric cars and leads to changes in their perceptions of contextual characteristics.

Further support for this stems from survey studies of large samples of electric car owners in Norway (for a detailed analysis, see Bobeth and Matthies 2016). Norway is experiencing an ongoing electric car boom, making such cars comparatively widespread among the population. In self-report studies, electric car owners state that the Norwegian government's broad monetary and non-monetary political incentive scheme was important for their decision to purchase an electric car (Figenbaum et al. 2014; Haugneland and Kvisle 2013). Owners report driving their electric car for all kinds of daily purposes and report extraordinarily high levels of user satisfaction (Figenbaum et al. 2014; Haugneland 2014; NAF 2015). Owners also evaluate many common concerns among non-users like limited range and insufficient charging infrastructure as much less relevant (Figenbaum et al. 2014). The studies also suggest that social norms communicated via personal networks may be very important for purchase decisions within the owners' social environment, as many owners reported having recommended purchasing an electric car to others (Haugneland 2014). A similar study of early German electric car owners supports most of these findings from Norway (Frenzel et al. 2015).

As encouraging as these studies are in terms of satisfaction after adoption and overall functionality, the combination of electric cars' apparent readiness for everyday use and a large package of political incentives may lead to a different kind of problem: In Norway, a significant number of electric car owners substitute what had previously been public transport trips with the use of their electric car (Figenbaum et al. 2014; Haugneland and Kvisle 2013; Klöckner et al. 2013). This is undesirable in terms of CO_2 emissions (given that the power for electric cars is not fully based on renewable energies) and other problems caused by car traffic mentioned in the "Transport sector challenges and electric car adoption in Germany" section. Such an increase in the usage of an energy-efficient technology (in comparison to the technology that was used before) prevents the full efficiency potential of the new technology from being realized and is often referred to as *rebound effect* (e.g., Berkhout et al. 2000). A satisfactory definition of the rebound effect that systematically reflects the complex causes and situational contexts of this phenomenon is still lacking and subject to a debate beyond the scope of this paper (Friedrichsmeier and Matthies 2015; Galvin 2014). However, for the sake of simplicity, we will stick to the term here. While Klöckner et al. (2013) found that both practical and financial reasons were partly responsible for the rebound effect in Norway, they also found indications that a psychological *moral licensing effect* (Sachdeva et al. 2009) was at work: Electric car owners' moral motivations to reduce car use were lower after the purchase than before.

The results of these user studies with large samples of electric car owners have been, to our knowledge, mostly ignored in the international scientific community so far, and have most certainly not been considered in the general public debate about electric cars in Germany (Bobeth and Matthies 2016).

Present study

From our literature analysis, we were able to identify three particularly interesting aspects that have not yet been sufficiently explored and fit into our research objectives (see the "The need for psychological research" section). First, the results of studies with experienced users suggest that a significant proportion of the general population currently overestimates the problems with electric car range and charging infrastructure. This is in line with findings from previous research showing the discrepancy between people's range preferences and objective range needs for everyday use (for an overview, see Franke and Krems 2013). Objective data from a representative sample of the German population show that, on average, 95% of privately-owned cars are driven less than 100 km per day, with only 12 car trips per year exceeding 160 km (Infas and DLR 2010; Öko-Institut 2011). The discrepancy could be caused by a phenomenon known as *range anxiety* (e.g., Nilsson 2011): People might fear running out of power while driving an electric car with no possibility of recharging nearby. Range anxiety should be lowered when people become aware that this scenario is highly unlikely with modern electric cars. Modern electric cars have reliable estimations of battery status and guide systems show the availability of charging stations in the area. Another explanation for the discrepancy is also plausible: People might have inaccurate perceptions of their range needs and tend to use the status quo, i.e., the familiar range values of their combustion engine cars, as a heuristic to judge electric cars' range (e.g., Kurani et al. 1994). If this is the case, the so-called range barrier for electric car adoption could be lowered by providing people with information about their objective range needs and emphasizing the implications for everyday usage. Taking these aspects into consideration, we formulated the following hypothesis:

> Hypothesis1: Range is perceived as less important when prospective users consider their actual range needs.
>
> Second, findings from studies with both non-experienced and experienced users clearly demonstrate the importance of the costs and benefits of financial incentives. Nonetheless, we know of no study systematically exploring how to counter possible rebound effects after the purchase of an electric car. Therefore, we wanted to explore the attractiveness of a subsidy that facilitates an alternative to car use: the use of public transport. As the potential effect of such an invented subsidy was unclear, we did not formulate a hypothesis, but rather an explorative research question. This research question was:
>
> Research question 1: Does a public transport subsidy, as a policy measure that indirectly provides financial benefits and could prevent rebound effects, have a positive effect on electric car adoption?
>
> Third, as indicated above, the role of social norms is still unclear. The *diffusion of innovation theory* (Rogers 2003) indicates that they ought to be highly relevant. Rogers assumes that, in early diffusion stages, people rely on evaluations from their social environment to form an opinion about an innovation that they have not experienced yet and know little about. However, we found only a few

and inconsistent findings on the importance of social norms in empirical studies. We assume that this is caused by methodological shortcomings, as studies with experienced users point to a high relevance of network effects. Nevertheless, these studies are explorative and do not test for significance. Our corresponding hypothesis was:

Hypothesis 2: Supportive social norms have a positive effect on electric car adoption.

Method

In the beginning of 2016, we conducted an online survey with 284 members of German households. The best approach to studying the factors behind electric car adoption in terms of external validity would be to investigate real-world purchase decisions. That was not possible for practical reasons, as electric car sales figures in Germany are too low to allow for a convincing sample. Therefore, we investigated our hypotheses by conducting a discrete choice experiment with a representative sample of new car buyers in the German population.

Discrete choice experiments build on *random utility theory* (McFadden 1974). According to this theory, people value products based on their utility. The utility of a product is composed of evaluations of the product's attributes, each of which contributes a certain share to the product's overall utility. When people are confronted with a decision between competing alternative products, they aim to maximize their utility, i.e., choose the product with the most preferable combination of attribute characteristics. Discrete choice experiments make it possible to study the relevance of different product attributes and attribute characteristics for consumers (Backhaus et al. 2011b; Hoyos 2010). Participants are asked to choose between alternatives defined as having certain attributes chosen on the basis of the researcher's theoretical assumptions. Usually, multiple decision situations are presented to the participant. While the attributes stay the same, the alternatives' characteristics with regard to each attribute are varied. Each attribute consists of one or more *attribute levels*, forcing the participant to make implicit trade-offs between alternatives with different attribute levels in order to choose the alternative with the maximum utility. The combination of a set of alternatives and their attribute levels is labeled a *choice set*. The mathematical decomposition of a participant's choices in multiple choice sets allows for the calculation of his or her preferences towards the attributes and attribute levels of interest for a product (or product category).

One main advantage of this method is its ability to simulate decision situations very realistically compared to other stated-preference measures (Hoyos 2010). The design of a choice set resembles decision situations that are familiar to people from their everyday lives. Another important advantage is that the evaluations of the attributes of interest are assessed implicitly, which means that several problematic biases known from self-report measures do not apply. This concerns especially the tendency to answer in a way that participants perceive as favored by others (*social desirability bias*; Fisher 1993). The tendency to answer as consistently as possible over the course of a study (*consistency bias*; Weisberg et al. 1996) is also lowered, as each choice set represents a new decision context. Furthermore, the method circumvents the memory distortions that tend to occur when people are asked to explain the underlying reasons for a decision they made in the past (*hindsight bias*; Roese and Vohs 2012). A main disadvantage of discrete choice experiments is that the number of attributes and attribute levels must be limited in order to reduce complexity for participants. Discrete choice experiments are based on the assumption of a compensatory decision process, which requires the simultaneous evaluation of all attributes (Backhaus et al. 2011a). However, the concept of *bounded rationality* indicates that people tend to base complex decisions on only a few factors while ignoring other aspects (Simon 1955). The implication is that the researcher has to choose the attributes and attribute levels very thoroughly in order to avoid obtaining irrelevant results (*garbage in, garbage out problem*; McQuarrie 2012).

The discrete choice experiment approach was useful in our case, as it provided a suitable framework for investigating our hypotheses. This will be explained in greater detail in the following subsections.

Design of the discrete choice experiment in this study

Before offering electric car purchase options, we first presented a scenario to our participants. We asked them to imagine that they travel approximately 20,000 km by car per year[3] and would like to buy a new middle-class car 2 years in the future. The latter was important because we wanted to investigate aspects that are not present in the real world at the moment, but might be soon (see below). Furthermore, participants were to assume that charging an electric car would always be possible at home and at the workplace. We also indicated that the network of fast charging stations in public spaces would be further developed than it is now and that charging would take 4 hours at home or at work and 15 min at public charging stations.[4] The charging time in our scenario is a little lower than for current electric cars, as we expected the technology to continue to develop over the next 2 years. The costs for electric cars and combustion engine cars were constant in our scenario: Middle-class electric cars had a purchase price of €25,000, while comparable combustion engine cars were priced at €20,000.[5] The operating costs of the electric car were fixed at €5.00 per 100 km, compared to €10.00 per 100 km for combustion engine cars. We framed the decision context rather optimistically because we wanted to present the purchase of an electric car as a viable option for households in the future, as we expect it to be from today's point of view.

After this introduction, we presented 12 choice sets to each participant. In each choice task, the participant had to indicate which of the three alternatives related to electric cars was most attractive to him or her under varying conditions (see Fig. 1 for an example choice set example). We limited the number of choice tasks for each participant to 12 in order to prevent fatigue (Backhaus et al. 2011b). The alternatives within the choice sets were defined according to four attributes labeled *grant*, *public transport subsidy*, *range*, and *diffusion*. Each attribute was scaled on three levels (see Table 1 for an overview of attributes and attribute levels). We will now describe the attributes and attribute levels in detail.

The first attribute, grant, was a much discussed government approach to fostering electric car diffusion in Germany at the time we designed the choice experiment. We included this attribute because research emphasizes the relevance of financial consequences in this particular decision context (see the "Theoretical background" section). The attribute levels were "no grant", "€ 2500" and "€ 5000". We chose this span because €5000 was the amount discussed most frequently among German media and policymakers at that time, although it was still unclear whether a grant would be introduced or not. We then also suggested a grant halfway between those two ends of the spectrum (€2500). When the participants took part in our choice experiment, the German government had not yet made a decision about introducing a grant.

The second attribute, public transport subsidy, represents a novel approach of indirectly offering financial incentives but simultaneously preventing the undesired effect of substituting public transport trips with electric car use. Our idea was based on the *BahnCard 100* offered by the main train service provider in Germany (Deutsche Bahn 2016). The BahnCard 100 comes in the form of a small, personalized card and is priced at approximately €4000. It allows its owner to travel with all train services nationwide as well as communal public transport in almost all German cities and regions for 1 year. For our study, we built upon this concept by eliminating the time limitation to make the offer even more attractive. Because of the innovative nature of the approach, the participants were given detailed information about how the subsidy would be implemented: They would be provided with a card for all forms of public transport (communal, regional, and national). They would use this card in lieu of payment whenever they chose to use public transport until the budgeted amount was used up. We scaled the subsidy at the same levels as the grant, as we wanted to compare the impact of the two attributes on the attractiveness of electric cars.

The third attribute, range, is usually communicated in kilometers on fact sheets and websites, in the media, and in many discrete choice experiments on electric cars and other alternative fuel vehicles as well (for an overview, see Hoen and Koetse 2014). To find out whether people's evaluation of range would change when they had more information about practical implications for their everyday usage of electric cars, we presented the same

[3] The average distance that households travel by car per year in Germany is approx. 14,300 km (KBA 2015).

[4] Charging a current middle-class electric car up to 80% of battery capacity takes at least 5 to 8 hours on typical power sockets. At fast charging facilities, the process takes between 20 and 60 min.

[5] The purchase price of middle-class electric cars in Germany is between 30 and 80% higher than comparable combustion engine cars. Detailed information on cost aspects of electric cars in comparison to combustion engine cars can be obtained from a web calculator at http://emob-kostenrechner.oeko.de/#/.

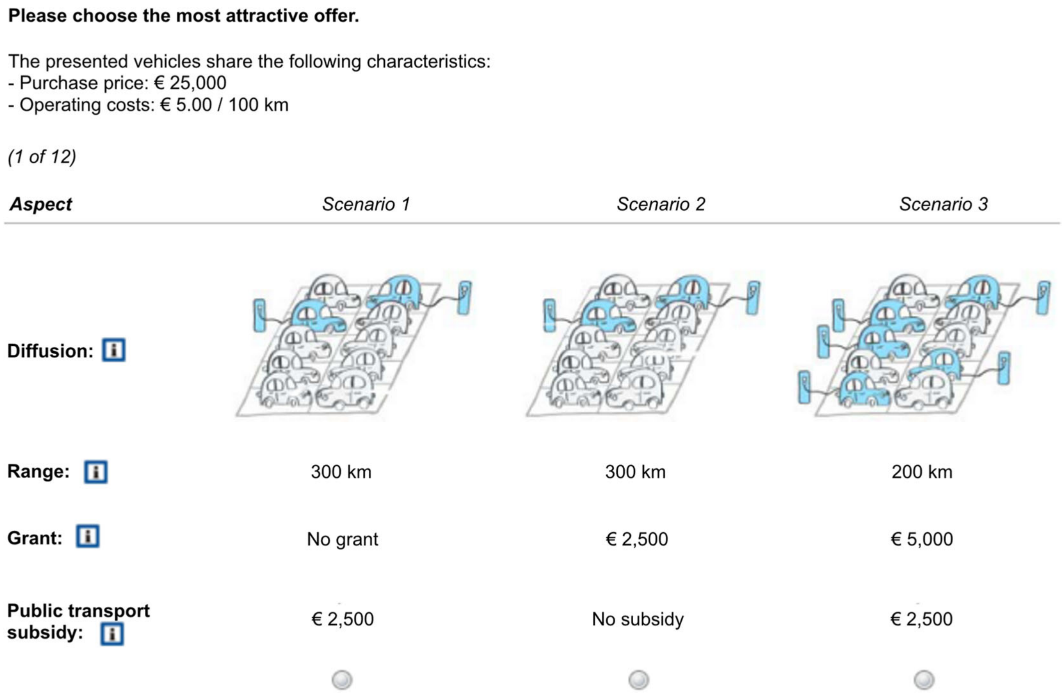

Fig. 1 Choice set example for participants who received range displayed in kilometers (option R1) and diffusion displayed as the share of electric cars on a parking lot nearby (option D1). Other participants received range displayed as the charging requirement per month (option R2) and diffusion displayed as people from the participant's social environment who drive and recommend electric cars (option D2). Each participant was assigned to only one of the four possible combinations throughout all choice tasks. The original study was conducted in German

range figures in two separate ways and randomly assigned participants to one condition or the other. In the first option (option R1), we used the usual method of displaying the attribute levels ("100 km," "200 km," "300 km"). We chose these attribute levels based on the fact that modern middle-class electric cars have a range within these limits (100 and 200 km) or will soon (300 km).[6] For the second option, our idea was to provide people with information about how often they would have to use public charging stations per month if they would like to use the electric car for the same trips for which they use the combustion engine car. For that, we translated the values from option R1 into the public charging required per month for an average German car user. We used information about average daily car driving patterns from a representative mobility study (Streit et al. 2015) and scaled the figures according to the 20,000 km that participants would drive annually with the car in our scenario. We were then able to present range information in the following way: "You are dependent on fast public charging once [or "twice", or "four times"] a month" (option R2). The figures we used were rather conservative, since our exact calculations resulted in an average public charging requirement of 4.0 times a month for a 100-km range, 1.6 times per month for a 200-km range, and 0.9 times per month for a 300-km range. We assumed that fast charging would always be possible at public charging stations as we expect the corresponding infrastructure to evolve quickly in the coming years.

The fourth attribute, diffusion, was included because we wanted to find out more about the importance of social norms. Social norms have rarely been included in choice experiments up to now (Kim et al. 2014), and when they have been included, they have been displayed in text format. We instead chose to indicate social norms with drawings, as we wanted to make the information more salient. We included two display options in the experiment in order to investigate research questions on the differences and similarities between different forms of social norms (*descriptive norms* and

[6] These are actually conservative estimations as the development of solutions for higher range in the electric car sector is currently very dynamic. The Tesla Model 3, which was introduced as a middle-class electric car in 2017, already has a range of 350km in the basic version and 500km in the more expensive version.

Table 1 Attributes and levels of the discrete choice experiment

Attributes	Levels
Grant	No grant
	€2500
	€5000
Public transport subsidy	No subsidy
	€2500
	€5000
Range	Option R1:
	100 km
	200 km
	300 km
	Option R2:
	You are dependent on fast public charging four times a month
	You are dependent on fast public charging twice a month
	You are dependent on fast public charging once a month
Diffusion	Option D1:
	2 out of 10 cars on a parking lot nearby are electric cars
	5 out of 10 cars on a parking lot nearby are electric cars
	8 out of 10 cars on a parking space lot are electric cars
	Option D2:
	2 out of 10 people in your social environment drive and recommend an electric car
	5 out of 10 people in your social environment drive and recommend an electric car
	8 out of 10 people in your social environment drive and recommend an electric car

Participants were randomly assigned to one of the four possible combinations of range and diffusion options (R1/D1, R1/D2, R2/D1 or R2/D2). They faced the same combination in each of the 12 choice sets. The original study was conducted in German

injunctive norms; Cialdini et al. 1990) that will not be discussed in this paper. To one half of the sample, we represented diffusion with a drawing that indicated the share of electric cars on a nearby parking lot (option D1). To the other half of the sample, we represented diffusion with a drawing that indicated approval of electric cars among assumed experienced users in the participant's social environment (option D2). The drawings indicated diffusion rates of 20, 50, or 80%, respectively. These attribute levels were based on findings from Kim et al. (2014), who reported that a diffusion rate of 50% within a social network is an important threshold above which people start to mimic the adoption of electric cars. They did not find any effects for market shares below 25%. We took these figures (we used 20% instead of 25% for reasons of display and comparability between the two options) and scaled the third level accordingly.

Analyses of the hypotheses and research question within the experiment design

The idea behind the analysis of discrete choice data is that each choice in favor of a given alternative (in a given choice set, by one of the participants) is based on the utilities that the alternatives have for that participant. The alternative with the highest utility is most likely to be chosen. As each of the attributes contributes to the utility of an alternative, we can estimate the influence of each attribute in a given context on the basis of the observed choices. This allows us to estimate the importance of each attribute in the presented decision context and compare the attributes with one another. The most suitable statistical method for this is mixed logit modeling (Train 2003), which is based on the assumption that not all aspects that are important for the utility of an alternative for a person can be included in the study. Thus, the function underlying the model takes unobservable factors into account as an error component (Hoyos 2010). Mixed logit models are able to overcome the limitations of other models (like the multinomial logit model) and have the advantage of allowing more flexible distribution assumptions for how unobserved factors enter the statistical model compared to other models (McFadden and Train 2000; Train 2003).

The mixed logit models for our data analysis were calculated with the R package *mlogit* (Croissant 2015). Our model was guided by Train and Croissant's (2012) applications of mlogit. We included the four attributes as alternative-specific variables that were all assumed to be normally distributed, used the Halton sequence with 100 draws, and took the panel structure of our data into account (for more information on the mathematical reasoning and steps of the simulation procedure, see Croissant 2012). In subsequent analyses, we also added interaction effects between all four attributes and variables of interest from the questionnaire to the formula (see the "Interaction of age and experience with the attributes" section).

Before we could evaluate our hypotheses and research question, we first had to specify them in the context of our experimental design. Hypothesis 1 was implemented in the form of the two different kinds of range display we presented. We expected the importance of range to be significantly higher for the group of participants who received range displayed in kilometers than the group who received range displayed as a charging requirement per month. To compare the importance of the two range displays, we looked at the odds ratio values of the attributes calculated by the mlogit procedure. Within the boundaries of our experiment, an odds ratio value higher than "1" can be interpreted as an increase in the likelihood of choosing an electric car when the attribute increases by one level (e.g., a grant of €5000 instead of €2500). An odds ratio value below "1" indicates a decrease in the likelihood of choosing an electric car when the attribute rises by one level (Field 2013). As we wanted to find out whether the differences in effects were significant, we performed a z test on the logit estimates behind the odds ratio values, as proposed by Paternoster, Brame, Mazerolle, and Piquero (1998; see the "Results" section for details).

Research question 1 was implemented in the form of the two attributes incorporating direct and indirect financial incentives. We wanted to find out whether or not the public transport subsidy we proposed would have a significant impact on the attractiveness of electric cars. Therefore, we analyzed the significance of the attribute in the mixed logit model on the basis of a t test included in the mlogit procedure. We also analyzed whether or not the effect of the public transport subsidy differed significantly from the effect of the grant (as a more conservative policy measure). For this, we performed a z test similar to the comparison of the two kinds of range displays described before.

To answer Hypothesis 2, we included the diffusion attribute in the experimental design. If social norms are indeed important for the attractiveness of electric cars, we would expect a significant odds ratio value for this attribute in the mixed logit model. As described above, we used a t test to test for significance.

Sampling procedure and sample characteristics

The participants in our online survey were recruited via an online panel provider. People interested in our study had to meet certain criteria in a screening process before they were allowed to participate. First, they had to indicate that they had bought a new car for their household in the last 56 years and that they were planning to buy another new car within the next 2 years. This was important because electric cars are usually bought as new cars at the moment, but only about one third of all car buyers in Germany buy new cars (DAT 2016). In addition, people interested in our study had to state that they were actively involved in the decision process for the purchase of their household's last new car. This was important in order to exclude passive household members who lack experience in the decision process for purchasing a new car. After this screening procedure, our final sample consisted of 284 members of German households.

In addition to the discrete choice experiment, we included several other questions in the survey, including questions about the participants' background. Table 2 compares our study sample to average new car buyers in Germany on key sociodemographic characteristics. The available data does not allow for significance tests, but

Table 2 Comparison of sociodemographic characteristics between our study sample and new car buyers in the German population

Sociodemographic characteristic	Sample (n=284)	New car buyers in German population
Age (years)		
29 and younger	15.8%	7.0%
30–39	25.0%	10.9%
40–49	22.5%	21.4%
50–59	24.6%	27.6%
60 and older	12.0%	33.1%
Gender		
Male	63%	66%
Female	37%	34%
Income		
€1500 and below	9%	6%
€1501–€2000	14%	9%
€2001–€5000	62%	70%
€5000 and more	15%	16%
Number of cars in household		
M	1.4	1.8
SD	0.6	(unknown)

Data about new car buyers in the German population was obtained from DAT (2015, 2016) and Statista (2016) face validity suggests that our sample was reasonably comparable in terms of gender, and was only slightly different in terms of income (our participants tended to have a lower income) and number of cars in the household (our participants tended to possess fewer cars). The main difference concerned age: The sample was notably younger than average new car buyers in Germany. Other interesting sample characteristics that we could not compare to the overall population due to a lack of available data are electric car experience and place of residence. Twelve participants reported that they owned an electric car, while three participants owned two or more electric cars (5% altogether). Fifty-five percent reported having no experience at all with electric cars, 33% reported having experienced an electric car once or twice, 7% three to five times, and 4% even more often. Thirty-three percent of participants reported living in cities with more than 100,000 inhabitants, 19% in suburbs of such cities, 29% in smaller cities, and 19% in rural areas.

As our sample differed in age from the population of German new car buyers, we decided to investigate possible interaction effects between age and the four attributes we included in the experiment. This is especially interesting for the range-related attribute, as older car buyers can be expected to have different range preferences than younger buyers. Due to their longer experience with conventional cars, they might have higher demands with regard to the constant availability of a car and the length of journeys they can undertake without interruptions (Franke and Krems 2013). Research on range preferences also suggests that more experience with electric cars might lead to acceptance of a lower minimum range for electric cars (see the "Theoretical background" section). A relatively small share of our participants had driven electric cars more than a few times. We decided to investigate a possible interaction effect between experience and range to investigate whether a more experienced sample would have evaluated range differently.

Results

Hypotheses and research question

We estimated a mixed logit model for the entire sample and two models based on the different range displays (option R1 or R2) that the two sub-samples received. Table 3 shows the resulting model estimations.

Excellent model fit is indicated by McFadden's pseudo R^2 lying between 0.2 and 0.4 (McFadden 1979), which was the case for all estimated mixed logit models. In all models, the four attributes entered the model significantly ($p \leq 0.050$). The estimated coefficients were positive for all attributes, which means that greater range, a higher grant or public transport subsidy, and greater diffusion all have a positive influence on choosing an electric car. In model 1, the overall model, grant has the highest odds ratio value, followed by range, public transport subsidy and diffusion. Range has the highest odds ratio value in model 2, followed by grant, public transport subsidy, and diffusion. In model 3, the odds ratio value of range drops below the odds ratio values of grant and public transport subsidy, but remains higher than diffusion. However, we cannot draw absolute conclusions from these values (such as "range is always more important than diffusion") as they are only valid within the boundaries of the specific attributes and attribute levels we used. Instead, we were interested in relative comparisons within and between the models.

To answer Hypothesis 1, we compared whether the coefficients for range were significantly different in models 2 and 3. This is possible with a z test developed by Paternoster et al. (1998). The authors introduced the following formula for the test:

$$Z = \frac{b_2 - b_3}{\sqrt{SEb_2 2 + SEb_3 2.}}$$

In our case, b is the range coefficient, SEb is the standard error of the range coefficient, and the indices stand for model 2 or model 3. The result of the test was $z=10.37$, meaning that the p value and thus also the difference between the two range coefficients was significant ($p=0.000$). Thus, range had a significantly lower odds ratio (i.e., importance for the perceived attractiveness of the electric car) when it was displayed as a charging requirement per month instead of in kilometers.

Research question 1 related to the significance of the public transport subsidy attribute for the attractiveness of electric cars. The attribute entered all models significantly and had a rather high odds ratio score. We performed z tests (using the same formula as above) to explore whether the odds ratio values

Table 3 Estimated mixed logit models

	Estimate	Std. error	Odds ratio	*t* value	*p* value
Model 1: overall model					
Range	0.94	0.05	2.57	19.05	0.000
Grant	0.97	0.05	2.63	20.03	0.000
Public transport subsidy	0.72	0.04	2.06	16.70	0.000
Diffusion	0.16	0.04	1.17	4.46	0.000
N	284				
df	3398				
Log likelihood	−2628				
McFadden's pseudo R^2	0.296				
Model 2: range displayed in kilometers (R1)					
Range	1.51	0.09	4.54	16.63	0.000
Grant	1.00	0.07	2.71	14.02	0.000
Public transport subsidy	0.77	0.07	2.17	11.57	0.000
Diffusion	0.16	0.05	1.17	2.97	0.003
N	139				
df	1658				
Log Likelihood	−1189				
McFadden's pseudo R^2	0.349				
Model 3: range displayed in charging requirement (*R*2)					
Range	0.41	0.06	1.50	7.39	0.000
Grant	1.08	0.07	2.94	14.84	0.000
Public transport subsidy	0.78	0.06	2.19	12.59	0.000
Diffusion	0.12	0.05	1.13	2.54	0.011
N	145				
df	1730				
Log likelihood	−1394				
McFadden's pseudo R^2	0.268				

for the public transport subsidy were significantly lower than those for the financial grant in each model. The difference was significant for the overall model (model 1; $z=3.74$, $p=0.000$) as well as for models 2 ($z=2.28$, $p=0.023$) and 3 ($z=3.07$, $p=0.002$).

Hypothesis 2 was about the influence of descriptive norms, which were implemented in the form of the diffusion attribute. Diffusion made a significant contribution to the choice of an electric car in all models, though the odds ratio value was clearly the lowest.

Interaction of age and experience with the attributes

As explained in the "Sampling procedure and sample characteristics" section, we found it useful to explore the influence of two specific characteristics of our sample on our results: age and experience with electric cars. Therefore, we estimated an additional mixed logit model for the overall model that included interactions between these two variables and the four attributes. Table 4 shows the resulting model estimations.

Two interactions were significant. The positive interaction between age and range indicates that older participants are more sensitive to range aspects than younger participants when assessing the attractiveness of electric cars. The negative interaction between experience and range indicates that participants with more electric car experience are less sensitive to range aspects than participants with less experience.

Table 4 Mixed logit model including interactions between age, experience, and the attributes

	Estimate	Std. error	Odds ratio	*t* value	*p* value
Range	0.88	0.20	2.42	4.33	0.000
Grant	0.98	0.21	2.67	4.65	0.000
Public transport subsidy	0.57	0.20	1.77	2.88	0.004
Diffusion	0.50	0.19	1.65	2.60	0.009
Age*range	0.01	0.00	1.01	3.39	0.000
Age*grant	0.00	0.00	1.00	1.31	0.191
Age*public transport subsidy	0.00	0.00	1.00	1.03	0.300
Age*diffusion	−0.01	0.00	0.99	−1.58	0.115
Experience*range	0.13	0.03	0.88	−4.12	0.000
Experience*grant	0.01	0.03	1.01	0.27	0.789
Experience*public transport subsidy	0.01	0.03	1.01	0.30	0.766
Experience*diffusion	−0.02	0.03	0.98	−0.72	0.473
N	227				
df	2706				
Log likelihood	−1964				
McFadden's pseudo R^2	0.342				

Discussion

In this section, we focus on the implications of our results for our three hypotheses. Then, we will discuss the generalizability of our findings. Finally, we will point out the implications of our research for policymakers.

Implications of the findings for our hypotheses

Hypothesis 1 addressed perceptions of range and charging infrastructure. Our results demonstrate the perceived importance of range aspects for electric car adoption, especially when range is displayed in kilometers, as it usually is. However, when we presented range in a way that makes its implications for everyday use more transparent to people not familiar with electric cars, the impact of range on the (un-)attractiveness of electric cars dropped significantly. This confirms our assumptions expressed in Hypothesis 1. We want to be clear about the fact that this finding does not mean that range and infrastructure aspects are unimportant altogether. But our participants seemed to overrate their importance in relation to the other attributes included in the experiment when their implications for everyday use were not explicitly communicated. The alternative framing of range information likely helped overcome people's knowledge gaps about their objective range needs and their consequent misperceptions about everyday electric car usage (e.g., need for public charging and car availability; see the "Present study" section). This is important as sufficient knowledge about sustainable behavior options is known to be a necessary, though not a sufficient, precondition for sustainable behavior (Abrahamse and Matthies 2013). While we expected a similar effect due to previous findings on range perceptions (e.g., Franke and Krems 2013; see the "Present study" section), we know of no other study that has demonstrated the impact of different ways of communicating range.

Research question 1 dealt with different types of monetary benefits. In relation to the given decision context and the other attributes, the provision of a grant was significantly more influential for the attractiveness of electric cars than a public transport subsidy. That was no surprise, since a grant is a direct financial incentive, while public transport subsidies have additional requirements that are only indirectly connected to car use. Nevertheless, the results also indicate that an innovative incentive approach that aims to strengthen public transport use following electric car adoption can have a significant and surprisingly large positive effect. To our knowledge, this is a new finding and thus still has to be confirmed by other studies. Whether such an incentive would indeed motivate electric car owners to use public transport until they exhaust the subsidized budget and beyond also has to be confirmed. We did not aim to conduct an in-depth exploration of the trade-offs between the two kinds of monetary benefits that we included. Therefore, answering the question of whether and to what extent a public transport subsidy could replace a grant is beyond the scope of our research. Further research should also explore the possibility of an additive effect between these two forms of incentives, which might have led to an underestimation of the odds ratio value for the grant and an overestimation of the odds ratio for the public transport subsidy. We also designed the subsidy in a way that encourages both local use of public transport and taking the train for longer journeys. While the latter might be an interesting option for everyone, we can expect regional differences in the effectiveness of such an incentive for local public transport use (see the "Transport sector challenges and electric car adoption in Germany" section): Switching to public transport is generally easier in larger cities than in smaller towns and rural areas. It is worth thinking about ways to stimulate alternative forms of sustainable mobility in these areas as well. For example, a public transport subsidy could be partly replaced or complemented with incentives for private car-sharing, as about half of car owners in rural areas show a willingness to carpool (more than in other regional contexts; Benthin and Gellrich 2017).

Hypothesis 2 investigated the role of social norms. Our data suggests that the diffusion rate in people's social environment *does* play a significant role in the attractiveness of electric cars. This is in line with Barth et al. (2016), who assume that social norms are undervalued in research on the adoption of electric cars. However, the odds ratio values do not indicate that supportive social norms are as powerful as financial or range aspects. This might be caused by methodological shortcomings: It is easier to appropriately present objective facts like financial aspects and range in a choice experiment than the many facets of social norms. In reality, people who recommend electric cars will probably mention several advantages, highlight ways of dealing with disadvantages and answer questions. They might also signal their status as a confident and satisfied user of a new technology very vividly. It was not possible for us to simulate social norms in such depth in this study. Consequently, we have to assume that, even though we found a significant effect, we might have still underestimated the influence of social norms in our findings.

Limitations and recommendations for further research

A major threat to the generalization of findings from controlled experiments like ours is differences in sociodemographic and other internal characteristics between study participants and the population of interest (Bortz and Döring 2006). In our case, the sample was much younger than new car buyers in the population are on average, and elderly new car buyers were particularly underrepresented. This was due to the priorities we set in the sampling process: The focus lay on the identification and recruitment of experienced new car buyers, not on an accurate representation of the target group (see the "Sampling procedure and sample characteristics" section). As the other sociodemographic aspects of our sample seemed reasonably comparable to the population of new car buyers in Germany, we assume that the underrepresentation of older people was caused by the age structure of the panel our participants were recruited from. This is a common characteristic of online panels (e.g., Hine et al. 2016). We suspect that older people might have a more conservative view on car range and accompanying aspects (see the "Sampling procedure and sample characteristics" section) and therefore perceive the range attribute as more important than younger people. The positive interaction found between age and range supports this assumption. Further research should test whether our results can be generalized to older new car buyers and explore the exact reasons for the empirical interaction effect in more depth.

Another sociodemographic factor that could threaten the generalizability of our findings is income. Although the income differences between our sample and average car buyers in Germany were not too big, lower income groups were slightly overrepresented. This could have led to an overestimation of the perceived importance of the two financial attributes, as income might have a higher perceived importance for lower-income households compared to high-income households. Our data did not allow for the exploration of a possible interaction effect because an income measure on an interval scale would be a precondition for such a test. Research on other energy-relevant investment decisions in households has only partly confirmed that income plays an important role in such decisions (Kastner and Stern 2015). Nevertheless, exploring the interactions between income and financial incentives is a task for further research.

Our focus in this study was to learn more about the next potential group of electric car adopters from today's perspective, i.e., a target group with low electric car experience. As we found a significant negative interaction effect between experience and the perceived importance of range, our findings should not be generalized to groups with higher levels of experience. However, this is a very small share of the population in Germany and in most other countries as well. Conversely, the advantage of our sampling approach was that we recruited participants who were familiar with purchasing a new car and were willing and financially able to do so again. Thus, our sample represents a group of potential electric car buyers within the next 2 years, as there will quite possibly still be no considerable second-hand market for electric cars during that time span. This is a group policymakers could legitimately target with support schemes right now.

In this study, our research interests required us to set up a self-contained decision context in order to integrate and test specific assumptions. If information such as an individual's target purchase price or distance driven annually could be assessed before the experiment, it would also be possible to tailor these factors individually in the choice experiment with a suitable algorithm and develop an even more realistic choice situation. For reasons of statistical validity, we prioritized the comparability of the decision situation across participants and framed the decision context as a plausible situation for a large share of new car buyers in the near future.

Implications for policy makers

A major goal of our research was to identify policy options that can accelerate the diffusion of electric cars. The results of our experiment suggest that the so-called range barrier can be diminished by communicating range-related aspects differently. A public transport subsidy as an indirect financial incentive proved to be an interesting option, and social norms should also be considered more prominently.

Policymakers and electric car marketers should tackle misperceptions related to insufficient electric car range rather than implicitly reinforcing range anxiety by consistently focusing on topics such as the need for range expansion in the electric car industry or expansion plans for public charging infrastructure. As our study shows, translating information on range (e.g., as presented in fact sheets about electric cars) into implications for everyday use can be very helpful: The range-related attribute was by far the most important attribute in our choice experiment when range was presented in kilometers, but it dropped to third place, when range-related aspects were translated into monthly public charging needs, as this made the implications for everyday usage and degree of fit with one's own mobility needs clearer for the participants. To help the overall image of electric cars and steer the public debate in a more constructive direction, we recommend launching well-designed informational campaigns that debunk the so-called range problem as a myth in many cases. Statements in the campaign should—again—underline the appropriateness of electric cars for everyday use. In doing this, they should be positive and carry the normative message that electric cars are socially desirable (Abrahamse and Matthies 2013). Positive aspects of the new engine should be emphasized as well: In many cases, electric car owners will no longer have to drive to a facility they would not visit otherwise (like a gas station), but will be able to comfortably charge at home (or at work, which should be supported by infrastructural measures). Intervention studies have demonstrated that informational campaigns are effective in increasing people's knowledge about the topic at hand (Abrahamse et al. 2005). In the context of everyday routines, provision of information is often a necessary, but not sufficient, precondition of change, as it often does not lead directly to a change (Ibid.). However, we can expect information provision to be much more important in the context of high-priced investment decisions. The far-reaching consequences of such a decision urge people to do enough research to make a well-informed decision (e.g., Gardner and Stern 2002). Thus, in the case of electric cars, policymakers should view informational campaigns as a necessary part of the support scheme and combine them with other incentives (e.g., subsidies and the use of social networks; see below).

Our findings on the effectiveness of a public transport subsidy should encourage researchers and practitioners to think outside the box and investigate innovative and comprehensive incentives. The development of subsidies that take undesired rebound effects into account could benefit the transport system as a whole. Of course, implementing a subsidy like the one in our study would require a joint effort by policymakers and public transport companies (e.g., in order to install an uncomplicated payment system that works for multiple public transport systems and also prevents the black-market trading of cards). Such a policy might also have promising long-term effects, as intervention studies have demonstrated that people might develop new routines when they are able to use public transport for free over a certain period of time (Bachman and Katzev 1982; Bamberg 2006; Matthies et al. 2006). This is especially the case when people commit themselves to the new behavior in oral or written form, which could be a precondition for receiving the kind of public transport subsidy we suggest.

Policymakers should also consider the significant influence of social norms when identifying target groups for support schemes. As explained in the "The need for psychological research" section, we can assume potential electric car adopters in the early diffusion stages to be especially responsive to supportive social norms. Therefore, the market introduction of electric cars should emphasize status aspects by making the advantages of driving an electric car more visible (e.g., with a special license plate or with free fast charging facilities offered in prominent places). Recommendations and information provided by early users are very important to users in later diffusion stages (Rogers 2003). In Norway, these network effects were fostered by well-designed websites and web forums[7] that enabled people who were interested in electric cars to receive information targeted to their interests and enter into an exchange with actual users (Haugneland and Kvisle 2013).

Conclusions

In this paper, we presented findings from a discrete choice experiment among German new car buyers. We showed that the way range aspects are communicated influences the perceived importance of range among potential electric car buyers. We also uncovered the potential of public transport subsidies as an innovative indirect financial incentive and of social aspects as a generally underestimated decision factor. These findings can be considered starting points for policymakers, who should strive to develop more effective and more comprehensive support schemes in order to achieve the urgently needed reductions in CO_2 emissions within the transport sector. Our findings are also important for researchers who study the factors behind electric car adoption and households' investment decisions. Further investigations of the effects of range myths, social norms, and innovative incentive approaches are needed to further validate our findings. We recommend exploring political support schemes based on our findings in practice, e.g., in field trials, to more effectively promote electric car diffusion.

[7] One example of a well-designed website that provides people with all kinds of information on electric cars is http://elbil.no. One example of a well-frequented web forum is http://elbilforum.no.

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Compliance with ethical standards

Conflict of interest for all authors The authors declare that they have no conflict of interest.

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