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Determinants of the acceptability of autonomous (cargo) mobility

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A R T I C L E I N F O

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A B S T R A C T

The transformation of the mobility sector is underway, and technological innovations such as autonomous driving are showing a way to set the future of mobility. In the implementation of new mobility offers, it is essential to consider aspects of acceptability research, as their use may directly depend on acceptability.

In this study, determinants of the acceptability of autonomous mobility were investigated using both a comprehensive questionnaire and a virtual reality study. The questionnaire results show that assessments of acceptability of autonomous driving, in general, are lower than the acceptability of specific autonomous vehicles, in this case, autonomous cargo bikes. For both, acceptability increases if (1) the object of acceptability is also expected to be highly beneficial, (2) environmentally friendly values or (3) an intention to use sustainable means of transport exist and (4) discomfort towards innovations such as digitalization is low. Furthermore, the assessment of acceptability varies depending on groups, e.g. between men and women, or between cyclists and car drivers.

Our virtual reality study showed that the possibility to experience interaction with autonomous vehicles has a positive effect on their acceptability and related variables.

Introduction

Analog to profound changes in energy production, mobility choices and preferences are fiercely discussed, moving intermodal mobility offers, alternatives to personal car use, and societal topics such as climate change into the foreground. One prominent topic is autonomous mobility (Madigan et al., 2016).

The estimates of the beginning of autonomous driving worldwide differ from 3 to 30 years to never. This might be due to different understandings of the requirements that are needed (Maurer et al., 2016). While most of the current research focuses mainly on cars (Maurer et al. 2016), several levels of society are engaged in this discourse. Mainly risks are discussed here, such as safety and trust in technology (Abraham et al., 2017). Autonomous mobility however also offers opportunities. One of them lies in the possibility of electric autonomous vehicles to reduce fuel consumption up to 20% and reduce CO_2 emissions by a similar extent (Barth & Boriboonsomsin, 2009; Igliński & Babiak, 2017). Similarly, efforts to reduce the number of road crashes and accidents (Knechel, 2015) are a main driving force behind the evolution of autonomous driving which would enhance both road safety and urban mobility (Forrest & Konca, 2007), creating a viable opportunity for the development of flexible mobility offer, smaller autonomous vehicles and environmentally friendly traffic.

Our research focuses on such micro-vehicles, i.e. autonomous driving cargo bikes (ACBs). While also tackling important aspects of future mobility such as reducing the total amount of cars and promoting the use of environmentally friendly mobility such as public transport, ACBs offer the opportunity to realize improved door-to-door mobility (Krause et al., 2020). The concept of autonomous Mobility-on-Demand gained a huge research interest in the last years, especially since such systems offer the opportunity to solve existing problems in bike-sharing, particularly fleet imbalance during peak hours (Salah, Mukku, Schmidt & Assmann, 2020). Such ACBs could therefore improve current bike-sharing offers – autonomously driving to user's selected starting points, manually driven by users in their desired purpose, and then finally – again autonomously – returning to a depot. Thereby, ACBs could avoid manual rebalancing problems of existing bike-sharing services and could offer more significant reductions in operational costs (Zug et al., 2019).

We were interested to determine the acceptability of introducing such autonomous cargo bikes in a larger German city. First, we were

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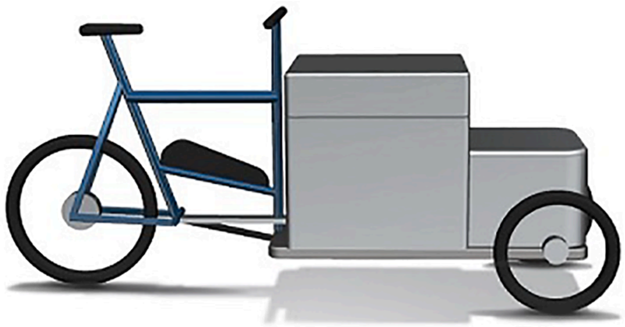

Fig. 1. Schematic representation of an ACB with three wheels and a cargo box system. Image created by Devina Manoeva, 2019.

interested to see which underlying psychological parameters were important to assess acceptability. Second, we did strive to understand how the level of acceptability may differ at baseline level and after experiencing the ACB in an immersive virtual matter. Since bikes share their paths with essentially all other road users, acceptability has to be assessed for different subjects.

This paper structures as follows. In the theory section, we offer the theoretical frame for our research, describing state-of-the-art acceptability research and relevant determinants that can be concluded from former studies. The method section informs on our approach and the statistical analysis used, offering results in the following section. At the end of the paper, we discuss our findings and summarise our conclusions.

Theory

Mobility is in transition – with autonomous driving and other innovations transforming this sector slowly, but thoroughly. Everyone participates in mobility one way or another, so very different groups of relevant actors – as in subjects of acceptability – must be taken into consideration when studying the acceptability of such innovations (Geels, 2005). Essentially, to what extent are we as a society prepared to accept a transport system in which fully automated vehicles are on the roads? Acceptability takes place within a broad framework of social and technical construction processes and is therefore interdependent on peoples' attitudes, expectations, and actions, corresponding values, and norms as well as contextual factors.

Current studies focusing on autonomous driving in general show trends of people being generally open towards this innovation (e.g. Continental, 2013; Schweizer-Ries et al., 2010; Lenz & Fraedrich, 2015). However, results differ with other studies pointing toward trust issues a significant portion of people (either road users or other participants in traffic) have with automated driving (for an overview, see Cartenì, 2020). Apart from that, there is, to the authors' knowledge, virtually no research on the acceptability of autonomous micro vehicles or autonomous cargo bikes yet.

A distinction between acceptability (before implementation) and acceptance (after implementation) emerges in technology research (Distler, Lallemand, & Bellet, 2018; Schuitema, Steg & Forward, 2010). While acceptance research focuses on objects such as new products and future users'/consumers' attitudes towards them (Lenz & Fraedrich, 2015), acceptability research takes social and public social willingness to accept a fully automated transport system into consideration. Distinguishing between different actor groups, such as citizens, users, consumers or other socio-political levels is relevant (Huijts et al., 2012a, Stern et al., 1999).

In our study, we focus on differentiating between objects of acceptability – the ACBs – and acceptability subjects – people interacting with the ACB, for example, other road users. Lenz and Fraedrich (2015) postulate a third category: the context of acceptability. In the case of this study, the context would be everyday urban mobility routines, in which object- and subject-related attitudes, perceptions, evaluations, and construction properties of the ACB are examined (see also Rauh, Appel & Graßl, 2020).

An ACB as this study's object of acceptability is developed as an autonomous transport bike with three wheels (Fig. 1), intended to supplement local public transport in everyday life. The bike will ride autonomously on designated cycle paths and interact with other road users following the road traffic regulations.

To understand why ACBs are being developed in the first place, it makes sense to consider them in connection with today's transport system. People often use different means of transport for one journey (e. g. a commuter first travels part of the way by train and covers the rest of the way by bus). Particularly on the so-called last mile, there are connection problems, e.g. due to a very long walk from the tram station to the workplace. Since there is a high demand for making urban environments and urban mobility more sustainable, the development of innovative concepts for the last mile that fulfill such requirements is becoming more and more of a priority. In current concepts, municipal, urban as well as corporate planners emphasize the importance of including cargo bikes in such concepts (Assmann, Lang, Mueller & Schenk, 2020). Cargo bikes are not only emission-free, environmentally-friendly vehicles, but also a viable means of transport in urban environments: their valuable benefit is the potential to reduce travel time for users over short distances in dense urban settlements, especially with higher traffic volumes (Assmann et al., 2020). Thus, they may be able to offer their users a continuous journey including the last mile, especially in settings where cars or other means of transport are not usable. Sharing systems for conventional and cargo bikes exist in many of today's large cities, but they contain a major challenge: fleet imbalance, meaning that borrowed bikes are often not returned to the station or no bikes are available, especially during peak hours (Salah et al., 2020). Redistribution is often expensive for operators of such sharing systems (Zug et al., 2019). This is where ACBs enter the picture to close such gaps, e.g. by solving the redistribution issue dynamically for operators – but above all to provide users with more comfortable mobility according to their needs. To reach this goal and to enable real door-to-door mobility, we develop an ACB ready to be integrated into a bike-sharing system of the 5th generation (Zug et al., 2019). ACBs will bridge existing gaps by autonomously driving to the user's desired starting point, e.g. their home, a train station, a supermarket, or their workplace. Then, users drive the ACB manually to their desired destination(s). Once all the paths for which the ACB was needed are done, the ACB autonomously returns to a waiting point, the depot, or the next user (see Krause, Assmann, Schmidt & Matthies, 2020 for further details).

There is consensus in current research that citizen acceptability is of great importance for the diffusion of such new technologies (Bögel et al., 2018). To access the acceptability of such a new mobility offer, different aspects have to be taken into consideration. As Distler, Lallemand, and Bellet (2018) point out, previous studies in the sector of acceptability of mobility offers have mainly used adaptations of technology acceptance models, such as the Unified Theory of Acceptance and Use of Technology (UTAUT, Venkatesh et al., 2003), or models that specialize in cars, such as the Car Technology Acceptance (CATM, Osswald et al., 2012) model. Analogies to other technologies and thus acceptability experiences from these areas tend to be difficult to establish. To the authors' knowledge, there is almost no research in this area on other autonomous vehicles or specifically ACBs. Furthermore, existing research on the acceptability of e.g. other technological innovations is rather difficult to transfer to autonomous driving, given its novelty. Although there are a lot of automated transport systems (e.g. aircraft, ships, (underground) trains, or military vehicles; Lenz & Fraedrich, 2015), most of them still operate using a human control or steering authority. For this reason, autonomous driving could also entail very specific requirements for acceptability. Therefore, there is a need to generate knowledge on the acceptability of specific autonomous vehicles.

Subjects interacting with such an ACB in daily traffic are either pedestrians or other bike/car drivers. While researching their acceptability, it is relevant to consider relevant psychological factors (Huijts et al., 2014). When relevant attributes are to be studied, psychology often distinguishes between internal and external factors. Internal factors describe causes or factors that may be „in“ a person, e.g. cognitive, emotional, attitudinal while external factors describe environmental attributes „outside“ of a person (Nerdinger and Horsmann, 2004; Guagnano et al., 1995). Following a typical distinction of dimensions, for example, attitudes and values relevant to acceptability could be assigned to internal factors, relevant actions to external factors. Depending on the object of acceptability as well as on the relevant dimensions, only specific indicators can be operationalized and measured in each case - which in turn inevitably excludes others (Lenz & Fraedrich, 2015). A careful selection is therefore necessary.

Huijts, Molin and Steg (2012b) proposed a comprehensive framework for the acceptability of technological innovations, i.e. in the energy sector. They combined findings from different studies to generate an overview of relevant determinants. In a combination of the Theory of Planned Behaviour (Ajzen, 1985) and the Norm Activation Model (Schwartz, 1977), such relevant aspects are for example prior experience and knowledge, positive and negative affects, cost, risk and benefit assessments, but also social and personal norms, perceived behavior control and attitudes. While Hujits et al.'s (2012b) framework summarise a lot of relevant constructs that have been often checked in previous studies, the framework may not be suitable for acceptability of a specific technology or vehicle, given the differences in scope between broad system changes like in energy production and distribution systems and specific modes of transport in daily life. Therefore, while this study referred to the findings of Hujits et al.'s (2012b) framework, the study space in terms of research was supplemented with further relevant aspects.

One of the first aspects of relevance here concerns the extreme innovativeness of autonomous mobility, as it is an innovative, relatively new, and relatively unknown technology for everyday life. Wolske, Stern and Dietz (2017) argue along the Diffusion of Innovations Theory according to Rogers (2003, cited according to Wolske et al., 2017) that looking at the innovativeness of people offers interesting conclusions for the acceptability of corresponding technologies. We assume that this can equally apply to the assessment of the acceptability of ACBs. As Wolske et al. (2017) further argue, innovativeness is also linked to how beneficial or harmful such technology is perceived to be. A corresponding cost-benefit assessment of their implementation is, therefore, of interest. Possible benefits do not only have to refer to financial or social aspects but can also include environmentally friendly aspects. Wolske et al. (2017) emphasize that an acceptable innovative technology must „fit in“ with existing needs, behavioral strategies, and values. Proximity to everyday life and the possibility of trying out or experiencing such a technology oneself also have an impact on acceptability. These aspects apply to ACBs.

Since our study concerns environmentally-friendly mobility alternatives, some aspects considering environmental value orientation (Bouman, Steg & Kiers, 2018) or environmental identity (e.g., Stern, Dietz, & Guagnano, 1995) are also to be considered. Results from prior studies showed that apart from perceived usefulness and perceived ease of use, environmental concern had a positive significant relationship with people's intentions to use autonomous vehicles (Wu et al., 2019). Trust emerged as another important factor (Liu et al., 2020).

The level of acceptability could further differ depending on the perspective from which road users are asked. For example, cyclists might find ACBs acceptable in a different way than motorists would, and pedestrians' perspectives might differ. Therefore, group identification with different road users (pedestrians, other bike drivers, car users, …) should be considered as well. Furthermore, the communication of autonomous vehicles with their surroundings could play a relevant role in acceptability (Krause et al., 2020). In prior studies, a comprehensive set of suitable communication strategies between an autonomous entity and other road users was selected and pilot tested (Manoeva, Gehlmann, Maiwald, Riestock & Schmidt, 2020). For example, findings showed that sounds similar to classic bike sounds (e.g. bells) were preferred, as well as simple, distinctive visual cues.

Surveys that directly test assessments of autonomous driving are currently still subject to the challenge that neither a broad level of knowledge nor concrete experience with the technology can be assumed. Such attitudes and assessments may therefore only be valid to a limited extent since the subject of the survey is not yet clearly defined because it is hardly known (see Lenz & Fraedrich, 2015). Furthermore, it is known from some studies that the possibility of directly experiencing or witnessing an acceptability object has an impact on acceptability (e.g. Pakusch & Bossauer, 2017; Martin et al., 2009; Shaheen et al., 2008). This underlines how important it is not only to measure acceptability in the abstract against a presented concept or object but - if possible - to use the possibility of establishing direct "contact" between objects and subjects to achieve more valid judgments.

In this context, the possibility of an (a priori) experience usually has a positive effect on acceptability. For example, Morra et al. (2019) found a direct effect between being exposed to an autonomous vehicle in a virtual reality environment and the willingness to test a real autonomous vehicle. Löcken, Golling and Riener (2019) tested the effects of presenting autonomous vehicles in virtual realities on trust, safety, and user experience, thus underlining that this particular form of research in the field of Human-Machine-Interaction is suitable for investigating such aspects.

The present studies approach the complex issue of the acceptability of autonomous vehicles in urban settings. Particularly, four research questions are focused on:

Research questions (study 1):

1. Which determinants can predict the acceptability of autonomous driving?
2. Which determinants can predict the acceptability of ACBs?
3. What are the group differences concerning the assessment of the acceptability of autonomous (cargo) mobility?

Research question (study 2):

4. What are the differences in terms of acceptability in indirect abstract and direct (virtual) contact with an ACB?

We approached these research questions in two study sets. First, a survey was conducted to generate insight on determinants of acceptability. To explore differences in different groups of road users, we conducted immersive experience studies with the ACB.

Study 1

Material and methods

Data collection procedure

A representative sample was drawn for a large German city (ca. 200.000 residents). For this purpose, the participants were contacted and recruited by direct mail (6000 letters were sent out in total) via the residents' registration office and an additional advertisement in a daily newspaper. The participants received a link to the online questionnaire or were able to complete the survey by telephone. Data were collected from April to June 2020. In Chapter 3.1.3., the sample will be described in detail.

Outcome Measures

Participants were asked to state the sex they identified with, their age, level of education, and monthly income. The questionnaire was in

German, so in the following section, we offer translated examples of the items used.

To measure whether participants were interested in pro-environmental aspects, we chose values following prior studies (see e.g. de Groot and Thøgersen, 2018 for an overview). Values were measured following Stern et al. (1998), asking participants whether the following aspects (altruistic, biospheric, conservative, egoistic, hedonistic) are guiding principles of their lives. On a 7-point-scale, participants rated values from „not important at all“ to „guiding principle“. Following the idea of this scale, biospheric values transport the idea of climate protection as a guiding principle whereas the other dimensions cover different value aspects.

To find out more about participants' norms, attitudes, or intentions toward climate-friendly mobility aspects, several measures were used. In detail, participants were asked about their personal norms (8 items, „People who are important to me expect me to use climate-friendly means of transport.”), environmentally friendly identity (New Ecological Paradigm, 8 items, „I am concerned about the environmental degradation caused by human resource consumption.”) and general attitude towards environmentally friendly traffic (3 items, „More environmentally friendly means of transport should be promoted with public funds.”), their perceived behavior control to use such modes of transport (PBC, 3 items, „If I want, I can choose a climate-friendly means of transport.”) and, consequently, their intention to use them (2 items, „I intend to use climate-friendly means of transport such as the bicycle or public transport.”, „In the future, I would like to (continue to) include the impact on the climate in my choice of transport.”).

To assess differences in car vs. bike mobility-related aspects, we were interested to know about participants' problem awareness concerning cars (3 items, „I worry when I think about the climate impact of driving.”) and their perceived dominance of cars (3 items, „The design of public space should give high priority to the use of the car.”). Furthermore, we used items to assess the attitude towards bike traffic (3 items, „Cycling should be promoted.”), attitude towards bikes (4 items, „I enjoy cycling.”), the perceived safety of bikes (3 items, „I am afraid of getting into an accident when I ride my bike.”), and satisfaction with bike infrastructure (3 items, „There is a sufficiently well-developed cycling infrastructure in [my city].”). To check for differences in perspective, we also asked participants if they identified with a specific group of road users most. The item was „I identify myself above all with other people who do most of their everyday walking as follows“, reply options were „by foot“, „by bike“, „by public transport“, „by car“, „others“; giving participants the option to fill in other options.

To gain further knowledge relevant for aspects concerning acceptability, we also assessed 4 items for the acceptance of technology (4 items, „I am always interested in using the latest technical equipment.”), and the general resistance against change (3 items, „I don't like to adapt to changes in my everyday life.”). We measured prior experience with cargo bikes as well as with autonomous driving. For cargo bikes, we asked people whether they had read or heard about cargo bikes, had seen one in daily life, or had used one. Participants indicated if this applied never, seldom, occasionally, or often. Analogue, they were asked if they had read or heard about autonomous driving if they had seen an autonomous gadget at work or home, if they used autonomous systems in their own car and if they had ever been driving inside an autonomous vehicle. Again, participants rated if this applied never, seldom, occasionally, or often.

The perceived benefit of autonomous driving was measured using 4 items („In my opinion, the introduction of autonomous driving brings many advantages for a climate-friendly traffic turnaround.”), analogous for the perceived benefit of ACBs („I am convinced that the introduction of autonomous transport bikes is a win–win for the population in the development towards climate-friendly transport.”). Participants replied using a 5-point-Likert scale, ranging from „do not agree at all“ to „fully agree“.

Participants were also asked how likely they would intend to use the ACB system once it would be implemented in real life. Reply options ranged from „not at all likely“ to „very likely“ on a 5-point-Likert-scale.

Table 1
Socio-demographic features of the sample Study 1 (n = 1099).

Characteristic	Sample Study 1	Population of the city the sample was drawn from
Gender	50,1 % male (n = 560)	49,9 % male (n = 117.828)
	49,1 % female (n = 549)	50,1 % female (n = 120.869)
	0,4 % diverse (n = 5)	
Age	min 18 years – max. 88 years	*M* = 47,6 years
	M = 40,57, *SD* = 16,305	
Level of Education	43% university degree (n = 477)	41 % university degree
		43,6 % A-levels, university entrance qualification
	24% A-levels, university entrance qualification (n = 265)	6 % without lower secondary school leaving certificate
	19% high school degree (n = 208)	
	7,2% Vocational baccalaureate (n = 81)	
	4,3% secondary school diploma (n = 48)	
	0,6% no degree (n = 7)	
Monthly Income	17,4% less than 900€ (n = 195)	11,6 % less than 900€
	10,1% 900 –1300€ (n = 113)	14,4 % 900 – 1300€
	7,1% 1301–1500€ (n = 79)	8,8 % 1300 – 1500€
	10,2% 1501 – 2000€ (n = 114)	17,5 % 1500 – 2000€
	13,1% 2001 – 2600€ (n = 146)	17,2 % 2000 – 2600€
	14,4% 2601– 3600€ (n = 161)	8,2 % 2600 – 3200€
	13.2% 3601 – 5000€ (n = 148)	
	6,6% 5001 – 18000€ (n = 74)	19,8 % more than 3200€
	0,1% more than 18000€ (n = 1)	

For measuring acceptability, several item sets were used. Both for acceptability of autonomous driving in general as well as ACBs, we used a 5-item set („I see the introduction of autonomous driving in Germany as a positive development for the future.”, „I would be worried if autonomous transport bikes were on the road in Magdeburg.” (reversed)). Here, participants replied using the same 5-point-Likert scale described above.

Additionally, two more items were used to measure acceptability: „How would you rate it overall if autonomous driving were introduced in Germany?” and respectively „How would you rate it overall if autonomous transport bikes were introduced in Magdeburg?”; in both cases participants replied via 5-point-liker scale, ranging from „absolutely unacceptable”, „rather unacceptable”, „undecided”, „rather acceptable” to „completely acceptable”.

For every measure, there was an „opt-out“ option named „no indication“.

The survey was split into two parts. In the first part, sociodemographic information and questions on aspects relevant to autonomous driving, in general, were asked. Then, participants were given an informational slide on both the AuRa project as well as the ACB. We included this information to ensure every participant was on the same level of information concerning such innovative technology. It can be found in the Appendix section at the end of this paper.

There were also other constructs used in this survey. However, they are not part of the results or content discussed in this paper and are therefore not mentioned here.

Sample

1116 people took part in the survey. After deleting cases who did not complete the entire survey as well as unreliable cases by controlling for missing values and answering time for the entire survey, the final sample consisted of 1099 people. Table 1 illustrates the sample characteristics. The proportion of women and men was balanced. Participant's ages ranged from 18 to 88 years with a mean of 40,57 years (SD = 16,31). Concerning the level of education, 43% reported having a university degree, 24% had a university entrance qualification, 19% had a high school degree, 7,2% had a vocational baccalaureate, 4,3% had a secondary school diploma, and 0,6% reported to have no degree. Monthly household income was less than 900€ for 17,4%, 2601-3600€ for 14,4%, 3601-5000€ for 13,2%, 2001-2600€ for 13,1%, 1501-2000€ for 10,2%, 1301 – 1500€ for 7,1% and 5001 – 18.000€ for 6,6%. One participant reported earning more than 18.000€ per month. In comparison to the general population of the city our study took part in, the study sample is very similar to the general population in terms of gender and income. However, the study sample's mean age is slightly younger, and study participants seem to be higher educated on average.

Analysis

The present study is an exploratory approach. The aim was to explore which determinants have significant relevance for the acceptability of autonomous driving on the one hand and ACBs on the other.

For this purpose, multiple linear regressions were calculated. It was decided to report significant predictors, even if their shares in the variance explanation are small since this is one of the first studies in this field. In the discussion (chapter 5), however, the predictors are interpreted once again with regard to their relevance.

On the other hand, we calculated group comparisons to explore differences in the acceptability of autonomous driving in general and ACBs in particular, and to differentiate between different roles of participants in road traffic. All analyses were performed with IBM SPSS Statistics Version 26.

Results Study 1

A linear regression with acceptability of autonomous driving as the dependent variable and a set of explanatory variables yielded some significant results, F (28, 1099) = 63.13, $p < .001$, with 66% of the variance in acceptability of autonomous driving explained by the following variables: perceived benefit of autonomous driving (β = 0.4; t (1099) = -4,18; $p < .001$), attitude towards autonomous driving (β = 0.34; t(1099) = 11.28; $p < .01$), perceived benefit of ACBs

(β = 0.13; t(1099) = 4,52 ; $p < .01$), perceived dominance of cars (β = 0.09, t(1099) = 3,39;

$p = .01$), biospheric values (β = -0.11, t(1099) = -4,03; $p < .01$), attitude towards bikes

(β = -0.06, t(1099) = -2,29; $p < .05$) and discomfort with digitalization (β = -0.05,

t(1099) = -2,12; $p < .05$).

Furthermore, acceptability of autonomous cargo bikes is related to a number of significant determinants, shows a linear regression (F (5, 1099) = 167,73, $p < .01$), with 43,7% of variance explained by the following variables: perceived benefit of ACBs (β = 0.502;

t(1099) = 15,85; $p < .01$), intention to use environmentally friendly means of transport

(β = 0.13; t(1099) = 3,41; $p < .01$), attitude towards autonomous driving (β = 0.11;

t(1099) = 3,29; $p < .01$), attitude towards ACBs (β = 0.1, t(1099) = 3,36; $p < .01$) and perceived dominance of cars (β = 0.06, t(1099) = 2,06; $p < .05$).

Across the board, autonomous driving is significantly less acceptable than ACBs (M_{AD} = 3.58; SD = 1.1; M_{ACB} = 3.85; SD = 1.03; $p < .01$, n = 1099). In addition, a gender effect for the acceptability of autonomous driving was found: Persons identifying as male have a significantly higher acceptability of autonomous driving than persons identifying as female (t(1101) = 5.1, $p = .01$; M_m = 3.24; SD = 0.57; M_f = 3.07; SD = 0.54).

Looking at the acceptability of ACBs, there is a significant group difference between subjects who identify more with cyclists vs. car drivers (t(707) = 0.63, $p < .05$; $M_{cyclists}$ = 3.33; SD = 0.58; $M_{cardrivers}$ = 3.2; SD = 0.53; $p < .05$) while cyclists find ACBs more acceptable than car drivers.

Table 2
Sample Characteristics in the Elbedome study.

Characteristic	Elbedome (n = 115)	Population of the city the sample was drawn from
Sex	55,7% female 43,5% male	50,1 % female (n = 120.869) 49,9 % male (n = 117.828)
Age	18–81 years M = 42,35 years (SD = 16,73)	M = 47,6 years
Level of Education	56,8% university degree (n = 67) 18,6% A-levels, university entrance qualification (n = 22) 14,4% high school degree (n = 17) 4,2% Vocational baccalaureate (n = 5) 1,7% secondary school diploma (n = 2) 0,8% other degree (n = 1)	41 % university degree 43,6 % A-levels, university entrance qualification 6 % without lower secondary school leaving certificate
Household Income	11,0% less than 900€ (n = 13) 8,5% 900 –1300€ (n = 10) 5,9% 1301–1500€ (n = 7) 15,3% 1501 – 2000€ (n = 18) 11,0% 2001 – 2600€ (n = 13) 16,1% 2601– 3600€ (n = 19) 10,2% 3601 – 5000€ (n = 12) 10,2% 5001 – 18000€ (n = 12)	11,6 % less than 900€ 14,4 % 900 – 1300€ 8,8 % 1300 – 1500€ 17,5 % 1500 – 2000€ 17,2 % 2000 – 2600€ 8,2 % 2600 – 3200€ 19,8 % more than 3200€

Study 2

Method and materials

One study in which a digital version of an ACB interacted with pedestrians was conducted in a mixed-reality laboratory. Due to the huge size compared to classic projection systems, the Elbedome laboratory at Fraunhofer IFF is suitable for the demonstration and interactive prototype visualization on a scale of 1:1 with a 360° panorama and floor projection surface, which makes it possible to move realistically and to scale in virtual worlds (Fraunhofer, 2020). Real urban settings from a German city were used in this virtual reality. Participants walked through the settings and encountered the ACB in typical traffic situations. A starting point to structure such scenarios can be done by looking at different paths or path types. In Germany, a typical set of urban paths includes a) separate paths for pedestrians, bikes, and cars or other motorized vehicles, b) shared paths for bikes and pedestrians, c) shared paths for bikes and cars or other motorized vehicles. Some variations may occur. Different speed regulations for bikes and motorized vehicles apply, too (Manoeva et al., 2020). In a prior study, relevant traffic scenarios were chosen (Manoeva et al., 2020).

Outcome Measures

Data were collected using two questionnaires. On the one hand, the participants answered questions while experiencing the different traffic scenarios in interaction with the ACB. Then, among other questions, they each answered 5 questions about their encounter with ACB. The items were worded as follows:

"I felt safe around the ACB."
"I found the signal from the ACB helpful in the situation."
"The ACB behaved as I expected it to."
"I can trust the ACB."
"I had the feeling that I could interact with the presented environment."

The last item dealt with the degree of immersion felt.

Secondly, after completing the scenarios, they answered another

Table 3
Results of the group comparison of relevant variables between study 1 and Elbedome samples.

Item	*p*	*m* study 1	*m* Elbedome	n
Likelihood of Use	0.000	3.35	3.78	97
PBC	0.000	4.13	4.48	86
Perceived Benefit of autonomous Cargo Bikes	0.000	3.83	4.13	82
Acceptability of Autonomous Cargo Bikes	0.000	3.53	4.19	75

short questionnaire (supplementary questionnaire in the following). In the supplementary questionnaire, measures already used in the survey for study 1 were used for comparability. Perceived behavior control, attitude towards environmentally-friendly mobility offers, perceived use of ACBs, attitude towards ACBs, acceptability of ACBs, and intention for using an ACB, were inquired again.

Measures concerning the virtual reality situation were added and participants stated their age, sex, level of education, and monthly net income.

Procedure and sample

The study was conducted in September 2020. Participants who already participated in the survey (study 1) were asked if they were willing to participate in one more study. 115 people took part in the Elbedome study. No cases had to be deleted.

Table 2 illustrates the sample characteristics. Slightly more women than men participated. Participant's ages ranged from 18 to 81 years with a mean of 42,35 years (SD = 16,73). Concerning the level of education, 56,8% reported to have a university degree, 18,6% had a university entrance qualification, 14,4% had a high school degree, 4,2% had a vocational baccalaureate, 1,7% had a secondary school diploma, and 0,8% reported to have another degree. Monthly household income was 2601 − 3600€ for 16,1%, 1501-2000€ for 15,3%, less than 900€ for 11%, 2001-2600€ for 10,2%, 5001-18000€ for 10,2%, 900-1300€ for 8,5% and 1301 − 1500€ for 5,9%. In comparison to the general population of the city our study took part in, the study sample is very similar to the general population in terms of income. However, the study sample's mean age is slightly younger, and study participants seem to be higher educated on average. Also, slightly more women participated in our study.

Results

In the comparison of relevant variables between the people who participated in the survey of study 1 and then were in the Elbedome, a longitudinal result in four aspects was found.

First of all, the likelihood of using the ACB system increased significantly in the sample which experienced a virtual interaction with the ACB (the Elbedome sample). Additionally, values for perceived behavior control, the perceived benefit of ACBs as well as the overall acceptability of ACBs increased significantly (Table 3). For the other variables, no significant group differences between study 1 and the Elbedome sample were found.

General discussion

Concerning the acceptability of autonomous driving in general, it is not surprising that its perceived benefit and a general attitude towards autonomous driving are relevant predictors here. The aspects of the perceived benefit of ACBs are also closely related, with ACBs being a sub-example or category of autonomous driving. The positive correlation with the perceived dominance of cars is also to be expected, for one, since in most urban settings cars are indeed dominant, and since autonomous driving is socially discussed in close connection with autonomous cars.

The negative significant correlations of biospheric values, an attitude in favor of cycling, and unease about digitalization are also consistent with the theory. Technological innovation does not necessarily have to go hand in hand with climate protection. Likewise, it can be assumed that autonomous mobility goes hand in hand with a high degree of digitalization so that unease towards one can be brought together with unease towards the other. The fact that people with an affinity for cycling view autonomous (car) mobility with skepticism also makes sense, since a "competitive situation" of the available road space can be assumed here.

However, some effect sizes we found were only very small. For example, discomfort with digitalization ($\beta = -0.052$) and perceived dominance of cars ($\beta = 0.064$) contributed very little to our overall investigation. For future research, it may therefore be useful to focus on the effects of the perceived benefit of autonomous driving ($\beta = 0.4$, and ACBs; $\beta = 0.5$) and attitudes towards autonomous driving ($\beta = 0.34$).

Looking at the results on the acceptability of ACBs, a similar picture emerges at first. Here, too, it is unsurprising and in line with the theory that the perceived benefit of ACBs is a strong predictor of their acceptability, as is the attitude towards autonomous driving in general and ACBs in particular. Regarding the result that the intention to use climate-friendly means of transport is also a positive predictor, it is assumed that ACBs are perceived as a substitute for cars - which are harmful to the climate - which also explains this correlation. Somewhat surprisingly, the perceived dominance of automobiles was found to be a positive predictor of the acceptability of ACBs. A possible explanation could be that when answering the items on perceived dominance of automobiles, it was mainly associated that cars are perceived as useful. Consequently, an ACB that can fulfill similar purposes of use as a car could be seen as an adequate substitute.

Regarding group differences, it is interesting that the assessment of acceptability can vary depending on the group, e.g. between men and women, or between cyclists and car drivers. First of all, it is in the scope of theories as well as the expectation that cyclists would report higher acceptability for ACBs than car drivers, since a substitution from standard bike to autonomous (cargo) bike seems closer than from a car to a bike-like mode of transport, therefore easier to accept for cyclists. Although a significant difference was found, the mean values of the two groups are quite close to each other, so that this group difference should not be overinterpreted and this substantive explanation may be acceptable in explaining it.

Looking at the mean values for the gender effect, the difference is substantially larger. Previous research showed, that some gender effects in mobility can be found. For example, Sandhu (2019) found a strong gender preference for the male gender in television commercials for automobiles, Granié and Papafava (2011) found that gender stereotypes are associated with driving, starting from the young age of 10 were children show very stable representations of male drivers, not so much for female drivers. This effect is also reported in gender differences found in judgments of traffic violations (Lawrence & Richardson, 2005), risk perception as well as consequences of crashed and accidents (Cordellieri et al., 2016). While there is no gender difference in risk perception, however, men and women differ in the degree of concern about this risk, with women showing more concern. The authors (Cordellieri et al., 2016) interpret this finding as the main difference between these two groups, which could also explain why men are more often involved in accidents and less concerned about road traffic, respectively. Considering these prior findings, a similar explanation for the effect found in our study could be assumed. Since this difference was only found for the acceptability of autonomous driving in general, but not for the acceptability of ACBs, we assume a minimal stereotype effect.

The results from our virtual reality study point in a direction that, in general, it seems a good idea to promote acceptability by offering possibilities to explore such innovative technologies such as autonomous vehicles more closely - even if virtually. We found that not only the


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Das Projekt AuRa

Im Projekt AuRa wird ein autonom, also **selbstständig fahrendes Transportrad** mit drei Rädern entwickelt. Es ist dafür gedacht, im Alltag den öffentlichen Personennahverkehr (ÖPNV) zu ergänzen. Das Rad wird selbstständig und rücksichtsvoll auf ausgewiesenen Radwegen fahren und sich gemäß der Straßenverkehrsordnung verhalten.

Die Abteilung Umweltpsychologie beschäftigt sich in einem Teilprojekt mit dem Mobilitätsbedarf in Magdeburg. Außerdem betrachtet sie, wie andere Verkehrsteilnehmende ein solches Transportrad wahrnehmen und bewerten.

Bildquelle: Devina Manoeva

Um nachzuvollziehen, warum überhaupt ein **autonomes Transportrad** entwickelt wird, ist es sinnvoll, dieses in Verbindung mit dem heutigen Verkehrssystem zu betrachten. Oft nutzen Menschen für einen Weg unterschiedliche Verkehrsmittel (z.B. eine Pendlerin fährt zuerst eine Teilstrecke mit dem Zug und legt den Rest des Weges mit einem Bus zurück).

Vor allem auf der sogenannten letzten Meile kommt es zu Anbindungsproblemen, z.B. durch einen sehr langen Fußweg von der Straßenbahnstation bis zum Arbeitsplatz. Hier setzt AuRa an und kann diese Lücke mit den Transporträdern schließen - und so eine durchgängige Reise von der Haustür bis zum Ziel ermöglichen.

Fig. 2. Screenshot of the informational input on the Aura Project and ACBs used in the questionnaire. Note: the name of the city was redacted by a black box here to ensure anonymity.

intended use (as a strong indication of its acceptability) of an ACB increased significantly with the possibility of a virtual encounter, but also values for perceived benefit and overall acceptability of ACBs were significantly higher. This is in line with prior findings, as we outlined in section 2. We found also significantly higher values for perceived behavior control, which indicates that a direct experience of the ACB enabled the participants to better assess whether such a means of transport would be an option for them and which range of means of transport are available at all.

Conclusions

In the societal challenge of (co)shaping the transformation of mobility, the results of acceptability research are relevant and should be considered. Our study underlines that autonomous mobility as an innovative technology could become useful in two respects through autonomous small vehicles: for one, they indicate higher acceptability values than autonomous driving in general, and secondly, in terms of sustainability, they could offer a more climate-friendly substitution of conventional automobiles, resulting in further advantages. Such advantages cover not only sustainable urban development in general but offer various opportunities to improve urban quality of life by tackling, for example, health aspects and circumventing problems of automobile traffic, not only limited parking spaces but also the quality of air. In combination with sharing offers, ACBs could also enliven public transport and offer new forms of participation in urban life for societies. These findings could be implemented into participatory approaches to redesign today's cities to make way for a better tomorrow.

Declarations

Availability of data and material

The datasets used and/or analyzed during the current study are not available due to privacy and data usage agreements.

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CRediT authorship contribution statement

Karen Kastner: Software, Validation, Investigation, Formal analysis, Writing – original draft, Visualization, Investigation. **Franziska Gehlmann:** Investigation, Methodology, Validation, Software, Writing - review & editing. **Sigrid Salzer:** Conceptualization, Supervision, Writing - review & editing. **Ingo Kastner:** Conceptualization, Methodology, Validation, Software, Writing - review & editing. **Ellen Matthies:** Conceptualization, Validation, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Fig. 2 shows a screenshot from the online questionnaire that was used to inform participants about the Aura project. Since the survey was conducted in German, the information was given in German as well. The text translates to:

"The AuRa project

In the AuRa project, an autonomous transport bike with three wheels is being developed. It is designed to complement public transport in everyday life. The bike will ride autonomously and considerately on designated bike paths and behave following road traffic regulations. The Department of Environmental Psychology is looking at mobility needs in *[lagre german city]* in a sub-project. It is also looking at how other road users perceive and evaluate such a transport bike.

To understand why an autonomous transport bike is being developed in the first place, it makes sense to consider it in connection with today's transport system. Often, people use different modes of transportation for one trip (for example, a commuter first takes a train for part of the way and then takes a bus the rest of the way). Especially on the so-called last mile, there are connection problems, e.g. due to a very long walk from the streetcar station to the workplace. This is where AuRa comes in and can close this gap with the transport bikes - and thus enable a continuous journey from the front door to the destination."

References

H. Abraham C. Lee S. Brady C. Fitzgerald B. Mehler B. Reimer J.F. Coughlin Autonomous vehicles and alternatives to driving: trust, preferences, and effects of age 2017 USA.

Ajzen, I., 1985. From Intentions to Actions: A Theory of Planned Behavior. In: Kuhl, J., Beckmann, J. (Eds.), Action Control. Springer, pp. 11–39. https://doi.org/10.1007/978-3-642-69746-3_2.

Assmann, T., Lang, S., Mueller, F., Schenk, M., 2020. Impact Assessment Model for the Implementation of Cargo Bike Transshipment Points in Urban Districts. Sustainability 12 (10), 4082.

Barth, M., Boriboonsomsin, K., 2009. Energy and emissions impact of a freeway-based eco-driving system. *Transportation Research. Part D. Transport and Environment* 14 (6), 400–410. https://doi.org/10.1016/j.trd.2009.01.004.

Bögel, P., Oltra, C., Sala, R., Lores, M., Upham, P., Dütschke, E., Schneider, U., Wiemann, P., 2018. The role of attitudes in technology acceptance management: Reflections on the case of hydrogen fuel cells in Europe. J. Cleaner Prod. 188, 125–135.

Bouman, T., Steg, L., Kiers, H.A.L., 2018. Measuring values in environmental research: A test of an environmental portrait value questionnaire. Front. Psychol. 9 https://doi.org/10.3389/fpsyg.2018.0056410.3389/fpsyg.2018.00564.s00110.3389/fpsyg.2018.00564.s00210.3389/fpsyg.2018.00564.s00310.3389/fpsyg.2018.00564.s004.

Carteni, A., 2020. The acceptability value of autonomous vehicles: A quantitative analysis of the willingness to pay for shared autonomous vehicles (SAVs) mobility services. Transportation Research Interdisciplinary Perspectives 8, 100224. https://doi.org/10.1016/j.trip.2020.100224.

Continental AG. (2013). Continental Mobilitätsstudie 2013. https://www.continental.com/resource/blob/12762/1ab71f91b3ae8246a404ae2562eef976/mobilitaetsstudie-2013-data.pdf.

Cordellieri, P., Baralla, F., Ferlazzo, F., Sgalla, R., Piccardi, L., Giannini, A.M., 2016. Gender effects in young road users on road safety attitudes, behaviors and risk perception. Front. Psychol. 7, 1412.

de Groot, J.I.M., Thøgersen, J., 2018. Values and pro-environmental behaviour. In: Steg, L.E., Van Den Berg, A.E., De Groot, J.I.M. (Eds.), Environmental psychology: An introduction. BPS Blackwell, pp. 167–178.

Distler, V., Lallemand, C., Bellet, T., 2018. April). Acceptability and acceptance of autonomous mobility on demand: The impact of an immersive experience 612, 1–10. https://doi.org/10.1145/3173574.3174186.

Forrest, A. D., & Konca, M. (2007). Autonomous Cars & Society [Unpublished Interactive qualifying Project]. Worcester Polytechnic Institute. https://web.wpi.edu/Pubs/E-project/Available/E-project-043007-205701/unrestricted/IQPOVP06B1.pdf.

I.F.F. Fraunhofer Elbedome: Das Mixed-Reality-Labor des Fraunhofer IFF Magdeburg 2020 https://www.elbedome.de/info/.

Granié, M.-A., Papafava, E., 2011. Gender stereotypes associated with vehicle driving among French preadolescents and adolescents. Transportation Research Part F: Traffic Psychology and Behaviour 14 (5), 341–353.

Geels, F.W., 2005. Technological Transitions and System Innovations: A Co-evolutionary and Socio-Technical Analysis. Edward Elgar Publishing.

Guagnano, G.A., Stern, P.C., Dietz, T., 1995. Influences on attitude-behavior relationships: A natural experiment with curbside recycling. Environment and behavior 27 (5), 699–718.

Huijts, N.M.A., Molin, E.J.E., Chorus, C.G., van Wee, G.P., 2012a. Public acceptance of hydrogen technologies in transport: A review of and reflection on empirical studies. In: Geerlings, H., Shiftan, Y., Stead, D. (Eds.), Transition towards sustainable mobility. Ashgate, pp. 137–164.

Huijts, N.M.A., Molin, E.J.E., Steg, L., 2012b. Psychological factors influencing sustainable energy technology acceptance: A review-based comprehensive framework. Renew. Sustain. Energy Rev. 16 (1), 525–531. https://doi.org/10.1016/j.rser.2011.08.018.

Huijts, N.M.A., Molin, E.J.E., van Wee, B., 2014. Hydrogen fuel station acceptance: A structural equation model based on the technology acceptance framework. Journal of Environmental Psychology 38, 153–166.

Igliński, H., Babiak, M., 2017. Analysis of the potential of autonomous vehicles in reducing the emissions of greenhouse gases in road transport. Procedia Eng. 192, 353–358. https://doi.org/10.1016/j.proeng.2017.06.061.

Knechel, N., 2015. When a crash is really an accident: A concept analysis. Journal of trauma nursing: the official journal of the Society of Trauma Nurses 22 (6), 321.

Krause, K., Assmann, T., Schmidt, S., Matthies, E., 2020. Autonomous driving cargo bikes – Introducing an acceptability-focused approach towards new mobility offer. Transportation Research Interdisciplinary Perspectives 6, 100135. https://doi.org/10.1016/j.trip.2020.100135.

Lawrence, C., Richardson, J., 2005. Gender-Based Judgments of Traffic Violations: The Moderating Influence of Car Type 1. J. Appl. Soc. Psychol. 35 (8), 1755–1773.

Lenz, B., Fraedrich, E., 2015. Gesellschaftliche und individuelle Akzeptanz des autonomen Fahrens [Social and individual acceptance of autonomous driving]. In: Maurer, M., Gerdes, J.C., Lenz, B., Winner, H. (Eds.), *Autonomes Fahren. Technische, rechtliche und gesellschaftliche Aspekte* [Autonomous driving. Technical, legal and social aspects]. Springer Vieweg, pp. 639–660.

Liu, L.u., Bouman, T., Perlaviciute, G., Steg, L., 2020. Effects of competence-and integrity-based trust on public acceptability of renewable energy projects in China and the Netherlands. Journal of Environmental Psychology 67, 101390. https://doi.org/10.1016/j.jenvp.2020.101390.

Löcken, A., Golling, C., Riener, A., 2019. September). How should automated vehicles interact with pedestrians? A comparative analysis of interaction concepts in virtual reality. In: In *Proceedings of the 11th international conference on automotive user interfaces and interactive vehicular applications*, pp. 262–274.

Madigan, R., Louw, T., Dziennus, M., Graindorge, T., Ortega, E., Graindorge, M., Merat, N., 2016. Acceptance of Automated Road Transport Systems (ARTS): an adaptation of the UTAUT model. Transp. Res. Procedia 14, 2217–2226.

Manoeva, D., Gehlmann, F., Maiwald, A., Riestock, M., Schmidt, S., 2020. *Introducing a road interaction-focused approach towards autonomous driving cargo bikes as a new urban mobility offer* [Conference presentation]. In: 2020 XXIX International Scientific Conference Electronics (ET). https://doi.org/10.1109/ET50336.2020.9238253.

Martin, E., Shaheen, S.A., Lipman, T.E., Lidicker, J.R., 2009. Behavioral response to hydrogen fuel cell vehicles and refueling: Results of California drive clinics. Int. J. Hydrogen Energy 34 (20), 8670–8680.

Maurer, M., Gerdes, J.C., Lenz, B., Winner, H., 2016. Autonomous driving: technical, legal and social aspects. Springer Open. https://doi.org/10.1007/978-3-662-48847-8.

Morra, L., Lamberti, F., Prattico, F.G., Rosa, S.L., Montuschi, P., 2019. Building trust in autonomous vehicles: Role of virtual reality driving simulators in HMI design. IEEE Trans. Veh. Technol. 68 (10), 9438–9450.

Nerdinger, F. W., & Horsmann, C. (2004, September). Psychologie und Controlling. In Controlling (pp. 665-682). Franz Vahlen.

Osswald, S., Wurhofer, D., Trösterer, S., Beck, E., Tscheligi, M., 2012. Predicting information technology usage in the car: towards a car technology acceptance model. In: In *Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pp. 51–58.

Pakusch, C., & Bossauer, P. (2017, July). User Acceptance of Fully Autonomous Public Transport. Proceedings of the 14th International Joint Conference on e-Business and Telecommunications (ICETE 2017) - Volume 2: ICE-B (pp. 52-60). https://doi.org/10.5220/0006472900520060.

Rauh, J., Appel, A., Graßl, M., 2020. Empirische Beobachtungen zur Akzeptanz des Pilotprojektes „Autonom fahrender Kleinbus" unter den Bürger*innen von Bad Birnbach. In *Autonome Shuttlebusse im ÖPNV*. Springer Vieweg, Berlin, Heidelberg, pp. 159–176.

Rogers, E.M., 2003. Diffusion of innovations. Simon and Schuster.

Salah, I.H., Mukku, V.D., Schmidt, S., Assmann, T., 2020. In: June). A Conceptual Model for the Simulation of the Next Generation Bike-Sharing System with Self-driving Cargo-Bikes. Springer, Cham, pp. 253–262.

Sandhu, N., 2019. Fueling gender stereotypes: A content analysis of automobile advertisements. Business Perspectives and Research 7 (2), 163–178.

Schuitema, G., Steg, L., Forward, S., 2010. Explaining differences in acceptability before and acceptance after the implementation of a congestion charge in Stockholm. Transportation Research Part A: Policy and Practice 44 (2), 99–109. https://doi.org/10.1016/j.tra.2009.11.005.

Schwartz, S.H., 1977. Normative influence on altruism. In: Berkowitz, L. (Ed.), Advances in experimental social psychology, Vol. 10. Academic Press, pp. 221–279. https://doi.org/10.1016/S0065-2601(08)60358-5.

Schweizer-Ries, P., Rau, I., Zoellner, J., Nolting, K., Rupp, J., & Keppler, D. (2010). Aktivität und Teilhabe–Akzeptanz Erneuerbarer Energien durch Beteiligung steigern [Activity and participation. Increasing the acceptance of renewable energies through participation; Final Report]. https://www.researchgate.net/publication/271197704_Aktivitat_und_Teilhabe_-_Akzeptanz_Erneuerbarer_Energien_durch_Beteiligung_steigern.

Shaheen, S.A., Martin, E., Lipman, T.E., 2008. Dynamics in behavioral response to fuel-cell vehicle fleet and hydrogen fueling infrastructure: an exploratory study. Transp. Res. Rec. 2058 (1), 155–162.

Stern, P.C., Dietz, T., Guagnano, G.A., 1995. The new ecological paradigm in social-psychological context. Environment and Behavior 27 (6), 723–743. https://doi.org/10.1177/0013916595276001.

Stern, P.C., Dietz, T., Guagnano, G.A., 1998. A brief inventory of values. Educ. Psychol. Measur. 58 (6), 984–1001. https://doi.org/10.1177/0013164498058006008.

Venkatesh, V., Morris, M.G., Davis, G.B., Davis, F.D., 2003. User acceptance of information technology: Toward a unified view. MIS quarterly 425–478.

Wolske, K.S., Stern, P.C., Dietz, T., 2017. Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories. Energy Res. Social Sci. 25, 134–151. https://doi.org/10.1016/j.erss.2016.12.023.

Wu, J., Liao, H., Wang, J.-W., Chen, T., 2019. The role of environmental concern in the public acceptance of autonomous electric vehicles: A survey from China. Transportation Research Part F: Traffic Psychology and Behaviour 60, 37–46.

Zug, S., Schmidt, S., Assmann, T., Krause, K., Salzer, S., Seidel, M., Wohlgemuth, V., 2019. BikeSharing der 5. Generation - Szenarien und Herausforderungen für den Einsatz autonom agirender Fahrräder. In: Marx Gómez, J., Solsbach, A., Klenke, T. (Eds.), Smart Cities/Smart Regions – Technische, wirtschaftliche und gesellschaftliche Innovationen Konferenzband zu den 10. BUIS-Tagen. Springer Vieweg.