I know it – I like it – I buy it! The role of knowledge for the adoption of battery-electric and hydrogen vehicles

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Abstract
Although research in different disciplines has demonstrated that education and information can lead to more sustainable attitudes and related behaviour, supporting the assumptions of Roger's Diffusion of Innovation Theory, other research points to a knowledge-behaviour gap. Thus, we shed light on the question of whether knowledge can help to accelerate the adoption of transport innovations and under which conditions. Specifically, this research paper extends the current findings regarding the knowledge-attitude-behaviour process in the adoption of electric vehicles (EVs) by focusing on different types of knowledge and including the adoption of hydrogen-powered fuel-cell electric vehicles (FCEVs).We present two empirical studies from Germany – one on the adoption of electric vehicles by employees (n = 1,174) assessing potential differences in subjective and objective knowledge and one on the adoption of EVs and FCEVs in the general population (n = 1,344) assessing differences in knowledge regarding the innovation's diffusion phase. Using mediation analyses, the results of both studies support the theoretical assumption and the expected process: Knowledge has a positive impact on the adoption intention of EVs and FCEVs; this effect is mediated by individuals' attitudes toward the technological innovation. Regardless of the innovation's diffusion phase, greater knowledge leads to a more positive attitude towards the innovation, and a more positive attitude leads to a higher adoption intention of the technological innovations. The effect appears stable: It remains for subjective and objective knowledge (Study 1), for different measures of adoption intention (Study 1 and Study 2) as well as for different technological innovations in the transport sector which are in different diffusion phases (Study 2). Details of the results, their impact for implementing new technologies in other areas as well as the role of the media will be discussed.

Introduction
Behavioural change and the adoption of sustainable innovations are essential components to tackle climate change. For the energy transition, the transition to a more sustainable transport system on the individual level appears crucial: 20 % of the yearly carbon emissions in Germany are caused by individual road transport (BMU, 2020). Thus, the transition from conventional cars to zero-emission vehicles (ZEVs) is essential to prevent the climate crisis' acceleration. There are different types of ZEVs, for instance, one can distinguish the most prominent types in the general population: electric vehicles (EVs) and hydrogen-powered fuel-cell electric vehicles (FCEVs). EVs include battery-electric vehicles (BEVs) and plug-in electric vehicles (PHEVs). It is important to note that PHEVs are no ZEVs but low emission vehicles. Currently, EVs are better known and more prominent on the roads than FCEVs. However, the share of EVs sales in Germany has only recently increased from 1.6 % in 2017, 1.9 % in 2018, and 2.9 % in 2019 to 13.5 % in 2020 (IEA, 2021). Despite the large increase during 2020 (which might be a result of public funding and/or the COVID-19 pandemic), EVs still present a minority amongst the vehicles on German roads. However, for preventing the climate crisis, it is

necessary that most vehicles become ZEVs. Why is the diffusion of ZEVs so slow? Among other potential factors (such as public funding and policies), individual factors might play a role (Hornik, 1989): It might be the fact that knowledge about the innovations is missing.

There is a vast amount of literature from different disciplines stating that if people only "knew more or better" regarding climate change, carbon emissions, and sustainable behaviour, they would behave more sustainably (e.g., Kaplan, 1992). Interestingly, the link between knowledge and behaviour is often not a direct one but an indirect one via attitudes. When gaining knowledge, new information is implemented in existing structures and thus might change the way people see and perceive something – knowledge might change people's attitudes and ultimately, lead to behavioural change. Regarding the adoption of EVs, research has demonstrated this effect: If people know more about EVs, their attitude as well as their adoption intention of EVs increases (Wang et al., 2018). However, there is another line of research demonstrating gaps in the knowledge-attitude-practice and knowledge-behaviour process, respectively (e.g., Rimal, 2000). Do early adopters of ZEVs know more about the innovations? Is there a direct knowledge-behaviour relationship for technical innovations in the transport sector? Does the knowledge-attitude-behaviour relationship apply for different technical innovations in the transport sector or is it a specific effect for EV, which cannot be transferred to other ZEVs?

Compared to EVs, FCEVs are currently mostly unavailable on the German market or cannot be adopted because the infrastructure is missing; thus, its diffusion is close to zero (Holzer, 2021). However, parts of the public discourse in Germany indicate that the future adoption of FCEVs is partly perceived more positively than the adoption of EV (for the German media discourse see e.g., Przybilla, 2020). One reason for this might be the type of knowledge that people have regarding the different technologies: BEVs and PHEVs are already available for several years and people have seen and understood the pros and cons, shared experiences and developed an attitude towards BEVs and PHEVs. Developing an attitude towards FCEVs is more challenging because experiences are still missing and thus, another, rather theoretical knowledge is only available and the level of knowledge is lower in the general population (compared to BEVs and PHEVs).

Based on Rogers' Diffusion of Innovation Theory (2003), the underlying process of the adoption of both ZEV technologies (EVs and FCEVs) is the following: People start collecting and gaining knowledge about the innovation, and – based on this knowledge – build an attitude toward the innovation. This attitude leads to the adoption (or rejection) of the innovation forming the process of innovation diffusion (Rogers, 2003). This process from knowledge through attitude toward behaviour will be assessed in the present research – for different types of knowledge and different technical innovations in the transport sector. Since ZEVs are central to achieve the goals of the Paris agreement in the transport sector, in the present paper, we aim to shed light on the role of knowledge in terms of the diffusion of different types of ZEVs. Can knowledge lead to an increase in the adoption intention of different ZEVs? Does the knowledge-attitude-behaviour (KAB) process differ for BEVs, PHEVs, and FCEVs?

THE INFLUENCE OF KNOWLEDGE ON BEHAVIOUR

In different disciplines, it is common ground that problem awareness can be increased by education and knowledge transfer (e.g., Wang et al., 2018). The increased awareness leads to a change in behaviour: the action of individuals become more sustainable, healthier or more altruistic. This theory underlies many real-world efforts. Information campaigns and education interventions aim to evoke behaviour changes that increase health or safety for individuals or even reduce energy usage and emissions for society as a whole. In social psychology, knowledge transfer in the form of education (e.g., regarding gay men and lesbian women, Bartoş et al., 2014) is even found to be one of the most effective interventions to reduce discriminatory attitudes and related behaviour. Studies examining the relationship between knowledge, attitudes and practice, so called KAP studies, started in the 1950s to assess the processes from knowledge to behaviour and were applied to different disciplines (Launiala, 2009). Consequently, the relationship between knowledge, attitude and behaviour appears interesting in terms of sustainability research and the adoption of ZEVs.

There are many models that are used to explain the adoption of technical innovations. Among the most prominent are the following: the Theory of Reasoned Action (TRA; Fishbein & Ajzen, 1975) and the Theory of Planned Behaviour (TPB; Ajzen, 1991), the Technology Acceptance Model (TAM), and a combination in the Unified Theory of Acceptance and Use of Technology (UTAUT, Venkatesh et al., 2003). Although these models differ in the assumed factors that influence a specific (sustainable) behaviour, they have in common that the effect on adoption intention is usually indirect: The effect of the different factors is mostly mediated by the intention or the attitude towards the innovation or towards the behaviour (Venkatesh et al., 2003).

The assumption of an indirect relationship between knowledge and behaviour is also described in Rogers' (2003) diffusion of innovation theory. Following this theory, the process of innovation adoption at the individual level follows a clear path with three phases: In the first phase, people collect and gain knowledge about the innovation (knowledge phase). Based on this knowledge, a positive (or negative) attitude toward the innovation is formed (persuasion phase) which eventually leads to the adoption (or rejection) of the innovation in the decision phase. These steps represent a knowledge-attitude-behaviour process for the diffusion and adoption of innovations.

This relationship was also demonstrated in the transport sector for electric vehicles: A Chinese research group (Wang et al., 2018) found that consumers' knowledge is positively related to the attitude and the adoption intention towards EVs (next to other variables that were examined such as perceived usefulness). Importantly, the study indicated a positive direct effect of knowledge on behaviour and adoption intention, respectively, as well as an indirect effect from knowledge via attitudes towards EV to the adoption intention. The interpretation of the results showed a hint in the direction that the lack of knowledge might be a psychological barrier for the adoption and acceptance of EVs (Wang et al., 2018). Moreover, it appears intuitive that people require (and acquire) more knowledge about a product before they are willing to buy it. Thus, the linkage between knowledge and behaviour is intuitive, well examined and was demonstrated in different areas with a first study transferring it to the transport sector and EVs. Is this result stable? Can it be transferred to other ZEVs? Is it the case that if people only "knew better", they would adopt ZEVs?

THE KNOWLEDGE-(ATTITUDE-)BEHAVIOUR GAP

Another stream of research points in another direction and assumes a knowledge-behaviour gap: There is evidence that an increase in knowledge does not necessarily lead to behavioural change, indicating that the assumed effects of knowledge on behaviour may be weaker than expected (e.g., Rimal, 2000) and/or may rely on additional (situation-specific) factors. In specific areas, the knowledge-behaviour gap can be observed in people with different levels of knowledge – such as children with little prior knowledge (e.g., in dictator games regarding altruistic giving; Blake, 2018) and in researchers as experts in their field (Whitmarsh et al., 2020). Moreover, there is evidence from different disciplines indicating a knowledge-behaviour gap, for instance, in the health sector where people know about healthy diets and the relevance of sports and activities but continue to follow their unhealthy eating habits (Rimal, 2000). In the transport sector, one recent study showed that climate change researchers fly more than researchers in other areas (Whitmarsh et al., 2020). This may appear paradoxical given the expertise of climate change researchers in sustainability. Consequently, the relationship between knowledge and behaviour can be questioned.

Moreover, there is literature regarding the attitude-behaviour gap, which shows that the indirect effect of knowledge on behaviour can also be weaker than expected because the link between attitude and behaviour is weak (e.g., LaPiere, 1934). Similarly, research has demonstrated that other factors are more relevant for predicting pro-social and pro-environmental behaviour than knowledge (Heeren et al., 2016). Consequently, to reduce these gaps, the conditions of the linkages need to be considered: For instance, there are methodological possibilities to reduce the attitude-behaviour gap (e.g., by measuring attitudes and the related behaviour in the same way with the same specificity; Armitage & Christian, 2003). Thus, the present research paper examines whether there is a knowledge-behaviour gap regarding the adoption of ZEVs and under what conditions is can be reduced.

Models like the UTAUT often do not include knowledge as a crucial variable to predict behaviour and adoption intention, respectively. Instead, Venkatesh and colleagues (2003) state that knowledge and attitude only impact innovation adoption, when other more important factors are neglected. One could argue that an emotional reaction such as range anxiety, even if not warranted, is one such factor that influences the adoption intention. However, range anxiety can be reduced by experience with the innovation (Franke et al., 2012) – which can be subsumed under gaining information and experience. Thus, there are different kinds of knowledge that influence adoption intention differently.

DIFFERENT TYPES OF KNOWLEDGE

The example of tackling an emotional reaction such as range anxiety with using an innovation shows that there is a difference between knowing about the existence and features of an innovation and the knowledge created by using an innovation. Even if people are knowledgeable of the innovation's existence and its basic functions and benefits, they might still not know how to use it and might not have experiences with it. Gaining practical knowledge is referred to as experience or trialability in existing transition and innovation models such as UTAUT (e.g., Venkatesh et al., 2003). Saaksjarvi (2003) splits experience into two elements, both representing a part of consumer knowledge: "[1] familiarity which is the number of product-related experiences … by the consumer, and [2] expertise, the ability to perform product-related tasks successfully" (p. 94).

This demonstrates that different types of knowledge exist and, consequently, many definitions: Regarding innovations, one can differentiate between the knowledge of the existence of an innovation and the knowledge on how to use the innovation. This is in line with Rogers (2003) who stated that someone gains knowledge when they learn of an innovation's existence and gain some basic understanding of its functions. We will differentiate the knowledge Rogers (2003) refers to from the knowledge of how to use an innovation, which we will call experience. Additionally, other differentiations of knowledge types are possible: For instance, one can distinguish between subjective and objective knowledge. The first is measured with self-report questions, while the latter is measured with tests or quizzes. For the present paper, we will adopt a broad definition of knowledge, defining it as "gaining new information", and thus subsuming all kinds of knowledge. However, examining the different types of knowledge seems valuable and thus, is considered to some extent in the present research.

THE PRESENT RESEARCH

In the present paper, we tested the diffusion of innovation process postulated by Rogers (2003) to examine whether a knowledge-attitude-behaviour process can be applied for innovation adoption in the transport sector, and specifically for different ZEVs. Can knowledge help to accelerate the adoption of technical innovations in the transport sector? There is research regarding the adoption of BEVs and regarding the knowledge-behaviour relationship. However, to the best of our knowledge, so far no research has tested the knowledge-attitude-behaviour process and Rogers diffusion of innovation theory for FCEVs, comparing the effects between different ZEVs and considering different diffusion stages. Next to this question, we assess the conditions under which the proposed knowledge-attitude-behaviour relationship is stable. More precisely, we test whether different types of knowledge lead to different effects of the knowledge-attitude-behaviour process. Thus, this research paper aims to shed light on these aspects of the relationship between knowledge and behaviour for the adoption of ZEVs to understand the conditions under which the knowledge-behaviour gap can be reduced to a minimum.

Study 1

The aim of the first study was to test the knowledge-attitude-behaviour process in terms of adoption intentions towards electric vehicles (EVs) including battery-electric vehicles (BEVs) and plug-in-hybrid electric vehicles (PHEVs). Although there is some evidence for an attitude-behaviour and knowledge-behaviour gap, when considering the vast majority of the literature, we derived the following hypothesis:

H1: More knowledge regarding battery-electric vehicles leads to a more positive attitude toward electric vehicles and a more positive attitude leads to a higher adoption intention of electric vehicles.

In addition to this literature-based hypothesis, as a sub-question, we explored whether the way in which knowledge is measured affects the outcome of the relationship, testing the effect of subjective and objective knowledge in an exploratory manner.

METHODS

This section outlines the sample and the procedure of data collection as well as the relevant variables and measures of the assumed knowledge-attitude-behaviour process of Study 1.

Participants

We collected data from 1,301 employees of 14 institutes of a large research association in Germany. A total of 6,819 people were contacted via their professional email-address, 1,174 answered the questionnaire completely, thus, their data was used for data analysis. After inspecting the data, no additional exclusion criteria were applied. The final sample consisted of 26 % (n = 309) women and 69 % (n = 815) men, 4 % (n = 49) did not want to report their gender and one person reported to be of unassigned gender (third option in German: divers).

The distribution of participants across age categories is displayed in Table 1. Due to the recruitment strategy, all participants were employed but differed in their educational level: 71 % (n = 834) completed tertiary or university education, 16 % (n = 187) higher secondary education (German: Abitur or equivalent), 8 % (n = 96) lower secondary education (German: Mittlere Reife or equivalent), 2 % (n = 26) chose *other*, and 3 % (n = 31) did not want to report their educational level. Regarding the power and planning of the sample size, a post-hoc sensitivity analysis with G*Power version 3.1.9.7 (Faul et al., 2009) showed that with this sample size, an effect size $f^2 = .01$ (small effect) could be detected (for linear multiple regression, R^2 deviation from zero, $\alpha = .05$, power $1 - \beta = .95$, number of predictors = 2). Consequently, effects of a very small size ($f^2 < .01$) cannot be detected with the present sample size. However, the sample size is large enough to detect small to large effects.

Procedure and Material

The data was collected via an online survey in Germany in Summer 2019. Participants were informed that the survey is part of a larger research project of their institute and that it will take about 10–15 minutes to complete. They did not receive any incentive for participation. Since the survey was implemented to serve several research purposes of a larger project, the questionnaire consisted of five sections (mobility habits and options, knowledge-attitude-behaviour process, further factors regarding EVs, potential use of charging stations, socio-demographic variables). Relevant variables for the present study were included at the beginning of the survey (after items regarding participants' mobility habits and transport options). For the analysis of the present study, we measured the following relevant variables: subjective knowledge, objective knowledge, attitudes, and adoption intention in terms of EVs. To avoid being a participant burden, the survey was designed in a short and economic manner.

Adoption intention

First, we measured participants' adoption intention with a single item by asking whether they own an EV, whether they have decided to buy an EV within the next three years, and whether they are interested in EVs. There was a fourth option stating that none of the above applied. Participants were able to choose multiple options, except for *none of the above* which was an exclusive answer. Since the scale represents different degrees of adoption intention, we create a metric score: Each participant received a score between 1 = *none of the above* and 4 = *I own a EV* with higher numbers demonstrating a higher adoption intention. If participants had chosen several options, they received the highest chosen adoption intention.

Attitudes toward EV

Next, we measured participants' attitudes toward EVs with a single item by asking their response to the following statement: *In general, I think electric vehicles are a good idea.* The 6-point Likert-scale was labelled 1 = *completely disagree*, 2 = *mostly disagree*, 3 = *rather disagree*, 4 = *rather agree*, 5 = *mostly agree*, 6 = *completely agree*. Thus, a higher score represents a more positive attitude toward EV.

Subjective knowledge

Then, participants answered four items measuring their subjective knowledge regarding EV (e.g., *I can explain in detail the difference between hybrids, PHEVs and BEVs by using examples.* and *If someone would like to buy an EV, I could provide helpful advice by choosing the right model*). Participants were asked to report whether the statement applies or does not apply on a 6-point Likert-scale labelled 1 = *does not apply at all*, 2 = *mostly does not apply*, 3 = *rather does not apply*, 4 = *rather applies*, 5 = *mostly applies*, 6 = *applies completely*. Thus, a higher score represents a higher subjective knowledge (Cronbach's $\alpha = .85$).

Objective knowledge

Afterwards, objective knowledge was measured using a quiz with 12 questions. Participants decided whether statements like *EVs need to get serviced more often than conventional cars* and *The range of EVs is higher in summer than in winter* were true or false. The statements were developed by two researchers working in the research field of electric mobility and were chosen to present a range of difficulties (from quite easy to rather difficult to answer). For each correct response, participants received one point and a sum of all points was calculated. Thus, a total of

Table 1. Distribution of participants across age categories in Study 1.

Age category	18–25	26–30	31–35	36–40	41–45	46–50	51–55	56–60	61–65	66–70	Not reported
Percent %	11	20	16	14	11	9	9	6	3	0	2
Frequency	127	232	192	161	124	107	102	67	31	3	28

Table 2. Descriptive Statistics including correlations between relevant variables.

	Mean (*M*)	Standard deviation (*SD*)	*Min, Max* (potential range)	1 Subj. knowledge	2 Obj. knowledge	3 Attitude	4 Adoption intention
1 Subj. knowledge	3.29	1.28	0.50, 6.00 (1 to 6)		.21***	.14***	.35***
2 Obj. knowledge	9.79	1.76	4, 12 (1 to 12)			.10***	.21***
3 Attitude	4.57	1.21	1, 6 (1 to 6)				.43***
4 Adoption intention	1.86	0.68	1, 4 (1 to 4)				

*Min = minimum, Max = maximum, n = 1,174, *** p < .001.*

12 points was possible and the scale ranged from 0 = *no objective knowledge* to 12 = *very high objective knowledge*.

Finally, participants completed other items regarding charging stations and their (potential) charging habits, received contact information in case of questions and were thanked.

RESULTS

We analysed the data using SPSS version 25. The following section outlines the descriptive statistics as well as the inference statistical analyses for hypotheses testing.

Descriptive Statistics

The descriptive statistics (mean, standard deviation, minimum, maximum, and range) as well as the correlation between the central variables are presented in Table 2.

All variables are significantly correlated with each other, demonstrating a relationship. A medium to large correlation is detected between attitudes and adoption intention. The correlation between the variables shows that subjective knowledge correlates more highly with attitude towards EVs and adoption intention than objective knowledge. However, the correlations do not differ very much in size. One can state that the higher the subjective and objective knowledge of a person, the higher their intention to buy EVs. The same applies for attitudes: The more positive the attitude toward EVs, the more likely is it that the person will buy an EV.

The variables differed in their response scale (e.g., Likert-scale from 1 to 6 vs. Likert-scale from 1 to 12). Thus, we mean-centered all variables to conduct inference statistical analyses. In the following analyses, p-values below .05 indicate significant results.

Mediation Analyses

To test the hypothesis of Study 1, we conducted a mediation analysis (PROCESS version 3.5, Model 4) with objective knowledge as independent variable, attitude toward the innovation as mediating variable and adoption intention as dependent variable (all mean-centered). If not stated differently, we report bias-corrected 95 % confidence intervals based on 10,000 bootstrap re-sampling, as recommended by Hayes (2013). The mediation analysis revealed significant direct and indirect effects: Objective knowledge influenced the attitude towards the innovation positively, a = .07, beta = .10, p < .001, 95 % CI [0.03; 0.11], and the attitude impacted adoption intention, b = .23, beta = .41, p < .001, 95 % CI [0.20; 0.26], demonstrating a significant indirect effect, ab = .02, 95 % CI [0.01; 0.03]. In addition, objective knowledge had a significant direct effect on adoption intention, c = .07, beta = .17, p < .001, 95 % CI [0.05; 0.09].

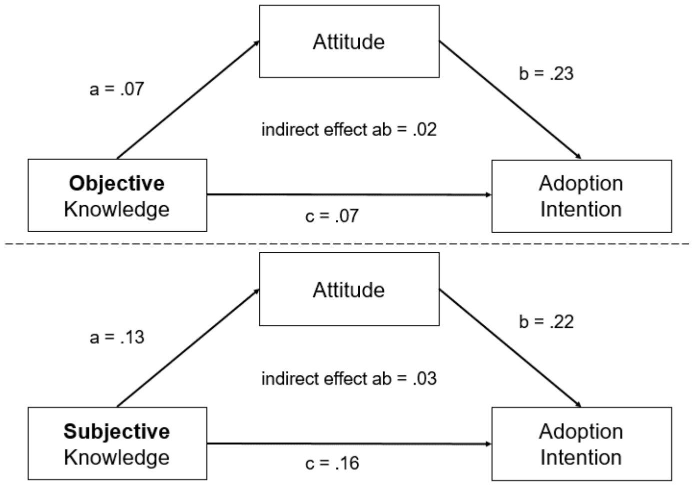

Figure 1. The significant mediation effect of subjective (lower panel) and objective knowledge (upper panel) on adoption intention via attitude.

In addition, to explore a potential difference in the relevance of objective and subjective knowledge, we conducted the same mediation analysis (Model 4) with subjective knowledge instead of objective knowledge as mediator. The pattern of results remained: Subjective knowledge had a positive impact on the attitude toward the innovation, a = .13, beta = .14, p < .001, 95 % CI [0.08; 0.18], and a positive attitude led to a higher adoption intention, b = .22, beta = .39, p < .001, 95 % CI [0.19; 0.25], demonstrating a significant indirect effect, ab = .03, 95 % CI [0.02; 0.06]. In addition, objective knowledge had a significant positive direct effect on adoption intention, c = .16, beta = .30, p < .001, 95 % CI [0.13; 0.19]. Results of both mediation analyses are pictured in Figure 1.

DISCUSSION

The data support our hypothesis of a knowledge-attitude-behaviour relationship. Our analyses demonstrate that having greater knowledge about EVs leads to a more positive attitude towards them which, in turn, has a positive impact on adoption intention of EVs. The sample of Study 1 might be a limitation:

Due to the self-selection of the employees, we did not reach a representative sample. The sample was rather male, highly educated and – due to the recruitment via a larger German research institute – employed, leading to the assumption that the income was also rather medium to high. These characteristics are indicators for the adoption of EV (Plötz et al., 2014; Vassileva & Campillo, 2017). Thus, replicating the study with a representative sample to further examine the effects found and to assess the knowledge-attitude-behaviour process would be valuable. Additionally, the measure of adoption intention allowed participants to select several response options and one could discuss whether the calculation of the score represents a metric variable. Thus, a different measure for adoption intention should be implemented when replicating the study. Moreover, the order of the measure did not resemble the expected knowledge-attitude-behaviour process. This should not change the statistical analyses. However, it would be more methodologically sound if knowledge could have been measured before attitudes and attitudes before the adoption intention. Hence, we conducted a second study including these changes.

Study 2

The aim of Study 2 was to replicate and further support the knowledge-attitude-behaviour effect found in Study 1 for EV. Since we did not find (large) differences between subjective and objective knowledge in Study 1, we implemented only the measure of subjective knowledge in Study 2. To overcome the limitations of Study 1, we used a more precise measure for adoption intention and tested the effect of knowledge on EV adoption intention in a representative sample.

To also answer the remaining question of Study 1, whether the knowledge-attitude-behaviour effect can also be transferred to other types of ZEVs, we tested the effect for different ZEVs – not only for BEVs but also for PHEVs, a very similar innovation, and for FCEVs. We examined the role of knowledge on the adoption intention of FCEVs, because FCEVs are currently at a different diffusion stage than BEVs and PHEVs. Since experiences with EVs exist but those with FCEVs are missing, representing the knowledge of use, the perceptions of EVs and FCEVs differ. One could assume that results differ depending on the technical innovation's diffusion phase because knowledge based on practical experience regarding FCEVs is lower and thus, the overall effect of knowledge might be weakened. On the other hand, it is also possible that the effect remains since the underlying theory of the knowledge-attitude-behaviour relationship (demonstrated in Study 1) is the same. Also, the innovations (BEVs and PHEVs vs. FCEVs) resemble each other and remain in the category of technical innovations and in the transport sector. More specifically, although PHEVs are no ZEVs but low emission vehicles, the innovations (BEVs, PHEVs, and FCEVs) remain within the category of ZEVs (or low emission vehicles). Thus, Study 2 assesses the role of knowledge on the adoption intention of BEVs, PHEVs and FCEVs as technical innovations in the transport sector to extend the results of Study 1. We tested the following hypotheses:

- Hypothesis 1: More knowledge regarding *battery-electric vehicles* leads to a more positive attitude towards battery-electric vehicles and a more positive attitude leads to a higher adoption intention of battery-electric vehicles.
- Hypothesis 2: More knowledge regarding *plug-in-hybrids* leads to a more positive attitude towards plug-in-hybrids and a more positive attitude leads to a higher adoption intention of plug-in-hybrids.
- Hypothesis 3: More knowledge regarding *hydrogen vehicles* leads to a more positive attitude towards hydrogen vehicles and a more positive attitude leads to a higher adoption intention of hydrogen vehicles.

Additionally, Study 2 explores whether the diffusion stage has an impact on the effect of knowledge via attitudes on the adoption intention.

METHODS

As for Study 1, this section outlines the sample and the procedure of data collection as well as the relevant variables and measures of the assumed knowledge-attitude-behaviour process of Study 2.

Participants

In cooperation with a market research institute, we recruited a sample of 1,779 persons. Since the survey served additional research purposes, participants were inhabitants of 83 German cities with a population greater than 100,000. The sample was recruited using fixed quota for age, gender, education and regional distribution being representative for the German population in urban spaces, following data from Eurostat (2020). Participants who did not complete all relevant variables for the present study were excluded. Thus, the final sample consisted of 1,344 participants of which 42 % (n = 559) identified as female, 58 % (n = 783) as male and two participants as of unassigned gender (third option in German: divers), aged between 19 to 86 years (M = 50.44 years, SD = 14.80 years). The distribution across the age categories is displayed in Table 3. Regarding their educational level 35 % (n = 473) reported to have completed tertiary or university education as highest degree, 45 % (n = 598) higher secondary education (German: Abitur or equivalent), 15 % (n = 203) lower secondary education (German: Mittlere Reife or equivalent), 5 % (n = 69) completed primary education, and one person reported to have no educational degree. A post-hoc sensitivity analysis with G*Power version 3.1.9.7 showed that with this sample size, an effect size $f^2 = .01$ (small effect) could be detected (for linear multiple regression, R^2 deviation from zero, $\alpha = .05$, power $1 - \beta = .95$, number of predictors = 2). Consequently, to detect very small effects ($f^2 < .01$), a larger sample would have been required, but with the present sample size small to large effects can be detected.

Procedure and Material

For Study 2, the data was collected via an online survey in summer 2020, distributed by a market research institute. Since the survey served several research purposes, the questionnaire consisted of three sections (a choice experiment unrelated to this study's context, questions regarding the use of transportation during the pandemic and the items for this study and related research purposes). Relevant items for the present study are knowledge, attitudes and adoption intentions of the three ZEV innovations, namely BEVs, PHEVs, and FCEVs. First socio-demographic data were collected as well as mobility habits and transport options. Then, the personal relevance of a car and

Table 3. Distribution of participants across age categories in Study 2.

Age category	18–25	26–30	31–35	36–40	41–45	46–50	51–55	56–60	61–65	66–70	70+
Percent %	4	7	7	10	13	13	11	9	8	7	12
Frequency	47	91	99	132	170	168	146	125	111	99	156

participants' technical affinity were measured, followed by the variables relevant for the present study (knowledge, attitudes, and adoption intention). Most of the relevant variables were measured using single-items to ensure an economic survey design without being a participant burden.

Knowledge

We measured knowledge with one item for each innovation asking participants *how well do you know the following technologies? – FCEV, BEV, PHEV*, resembling the measure of subjective knowledge in Study 1. To avoid that participants need to decide rather in favour or against the statement (Jonkisz et al., 2012), in Study 2, we implemented a 7-point Likert-scale (instead of a 6-point Likert-scale), which was anchored 1 = *I do not know it at all* and 7 = *I could explain it in detail*. Thus, high values of these variables represent high knowledge regarding the innovations.

Attitudes

After answering questions regarding the use of different media, participants answered one item regarding each technology measuring their attitude toward FCEVs, BEVs, and PHEVs (*What is your general attitude towards the following technologies? – FCEV, BEV, PHEV*). The 7-point Likert-scale was labelled 1 = *very negative*, 2 = *negative*, 3 = *rather negative*, 4 = *neither nor*, 5 = *rather positive*, 6 = *positive*, 7 = *very positive*. Thus, higher values represent a more positive attitude toward the ZEVs.

Adoption intention

Next, participants were asked *Could you imagine using the following technologies in the future? – FCEV, BEV, PHEV*, measuring their adoption intention. This time, a 6-point Likert-scale was used labelled 1 = *definitely not*, 2 = *no*, 3 = *rather no*, 4 = *probably yes*, 5 = *yes*, 6 = *yes, for sure*. Thus, higher values represent a higher adoption intention of the respective technology.

Afterwards, participants answered further questions regarding alternative technologies for trucks, trust in different actors, future developments, different aspects regarding media and their media use, which are not relevant for the present study's purpose. At the end, they were thanked and received a small compensation for their time.

RESULTS

As for Study 1, data were analysed using SPSS version 25. We conducted descriptive and inference statistical analyses to test the literature-based hypotheses.

Descriptive Statistics

Study 2 focused on the knowledge-attitude-behaviour process in BEVs, PHEVs as well as in FCEVs, thus, comparing the different technological innovations in the transport sector. Descriptive statistics and correlations of the variables measuring knowledge, the attitude toward these innovations as well as the purchase intention are displayed in Table 4.

Descriptive statistics show that knowledge about BEVs is slightly higher (compared to the other innovations). However, the attitude toward FCEVs is most positive (independent of knowledge about FCEVs). The correlations are all significant. Interestingly, the correlations between knowledge, attitude and purchase intention within one innovation are the highest (compared to correlations across different innovations), demonstrating a first hint in the expected direction. Similar to Study 1, the variables differed in their response options (e.g., Likert-scale from 1 to 6 vs. Likert-scale from 1 to 7); thus, we mean-centered all variables to conduct inference-statistical analyses.

Mediation Analyses

We conducted a total of three mediation analyses (PROCESS version 3.5, Model 4) for each technological innovation in the transport sector – one for BEVs, one for PHEVs, and one for FCEVs. All three mediation analyses followed the same structure (see Figure 2): We included knowledge as independent variable, the attitude towards the innovation as mediating variable and adoption intention as dependent variable (all variables mean-centered).

The mediation analysis on BEV-related variables revealed significant direct and indirect effects: Knowledge influenced attitudes towards the innovation positively, $a = .23$, beta = .21, $p < .001$, 95 % CI [0.17; 0.28], and the attitude had a positive impact on adoption intention, $b = .66$, beta = .71, $p < .001$, 95 % CI [0.62; 0.69], demonstrating a significant indirect effect, $ab = .15$, 95 % CI [0.11; 0.19]. In addition, knowledge had a significant direct effect on adoption intention, $c = .25$, beta = .25, $p < .001$, 95 % CI [0.20; 0.30], supporting Hypothesis 1.

In the second mediation model, when entering the variables for PHEVs, the pattern of results resembled the first analysis: Knowledge influenced attitudes towards PHEVs positively, $a = .24$, beta = .27, $p < .001$, 95 % CI [0.19; 0.28], and the attitude impacted adoption intention also in a positive way, $b = .61$, beta = .61, $p < .001$, 95 % CI [0.56; 0.65], demonstrating a significant indirect effect and supporting Hypothesis 2, $ab = .14$, 95 % CI [0.11; 0.18]. In addition, knowledge had a significant direct effect on adoption/purchase intention of PHEVs, $c = .27$, beta = .31, $p < .001$, 95 % CI [0.23; 0.32].

To test Hypothesis 3 and to assess potential differences between technological innovations in different diffusion phases, we conducted the same mediation analysis for FCEVs. The mediation analysis on hydrogen-related variables also revealed significant direct and indirect effects: Knowledge influenced attitudes towards FCEVs positively, $a = .31$, beta = .37, $p < .001$, 95 % CI [0.27; 0.35], and the attitude towards FCEVs had a positive impact on the adoption intention, $b = .62$, beta = .58, $p < .001$, 95 % CI [0.57; 0.66], demonstrating a significant indirect effect, $ab = .19$, 95 % CI [0.16; 0.22]. In addition, knowledge had a significant direct effect on the adoption intention of FCEVs, c = .36, beta = .41, p < .001, 95 % CI [0.32; 0.40]. Thus, also Hypothesis 3 was supported by the data.

DISCUSSION

Results of Study 2 confirmed the results of Study 1: For BEVs, we replicated the positive effect of knowledge on attitude towards BEVs and from attitude on the adoption intention. Moreover, we found the same pattern for other technological innovations, more specifically for PHEVs an innovation in a similar diffusion phase as BEVs as well as for FCEVs – an innovation that is not yet available. Consequently, the three hypotheses of Study 2 were supported and we did not find differences in the expected process for different innovations in the transport sector. The expected knowledge-attitude-behaviour process appears stable for ZEV innovations: Increased knowledge leading to more positive attitudes, and more positive attitudes leading to higher adoption intentions – for BEVs, PHEVs, and FCEVs.

General Discussion

The present research aimed to assess the knowledge-attitude-behaviour process for technological innovations in the transport sector. With two empirical studies, we examined a potential knowledge-attitude-behaviour relationship as demonstrated in different disciplines and sectors. Study 1 focused on the objective and subjective knowledge towards EVs. Results of Study 1 revealed a direct effect of knowledge on adoption intention, for subjective *and* for objective knowledge, standing in contrast to the assumption of a knowledge-behaviour gap. Interestingly, we did not only find a direct effect but also an indirect effect: The higher the knowledge, the more positive the attitude towards the innovation, and the more positive the attitude, the higher the adoption intention. This is in line with the assumed knowledge-attitude-behaviour relationship.

Study 2 examined the role of knowledge on attitudes and adoption intentions towards technical innovations in different diffusion phases, more precisely towards BEVs, PHEVs and FCEVs. As expected, the data indicated the same result as Study 1 demonstrating a direct and indirect effect of knowledge on adoption intention (mediated by attitudes towards the innovations). With its coverage of three related technologies and a larger, representative sample, Study 2 supports and extends the results of Study 1.

To sum up, the expected knowledge-attitude-behaviour process according to Rogers' Diffusion of Innovations Theory (2003) was supported by the data of both studies and appears stable for technical innovations in the transport sector, specifically for ZEVs. Although the knowledge-attitude-behaviour process appears to be intuitive, this study is the first one demonstrating its evidence for FCEVs empirically (and comparing different types of ZEVs). Future research could test whether the found knowledge-attitude-behaviour relationship also applies for the adoption of other (technical) innovations outside the transport sector.

Interestingly, the correlations and the mediation analyses revealed higher effect sizes for attitudes than for knowledge. This means that the attitudes towards the innovations are slightly better predictors for adoption intention than knowledge. Similarly, the results of Study 1 showed that subjective knowledge appears to predict the adoption intention slightly better than objective knowledge. Nonetheless, to accelerate the diffusion of ZEVs, we recommend to consider all three variables – to achieve subjective and objective knowledge as well as creating a positive attitude towards ZEVs – because all three have a significant impact on the adoption intention of ZEVs.

The fact that we found a knowledge-behaviour relationship for the studied innovations is a positive signal. However, four aspects need to be considered when interpreting the findings. First, our survey items do not measure concrete purchasing decisions of individuals but self-reported adoption *intentions*. Hence, in real life situations, the difference between knowledge and behaviour could be larger. Further research should examine whether knowledge has an impact on actual behaviour and the purchase of ZEVs, respectively.

Second, both of our samples were large enough to detect even small effects in the knowledge-attitude-behaviour process. This means that the results might not be as clear for smaller population groups such as the employees of one specific company. Additionally, the sample of Study 2 included mostly participants from large(r) cities, thus, replicating Study 2 with participants from rural and urban areas could be interesting to assess potential differences in the perception of FCEVs in rural and urban populations.

Third, the studied innovations are currently in different diffusion phases: BEVs and PHEVs are already widely available

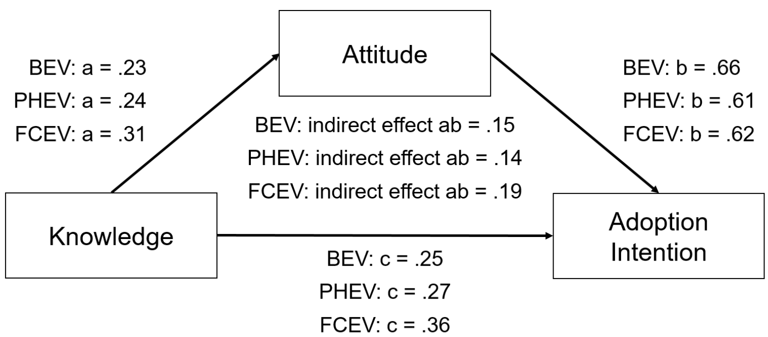

Figure 2. The significant knowledge-attitude-adoption process for BEV, PHEV, and FCEV.

Table 4. Descriptive Statistics including correlations between relevant variables.

	Mean (*M*)	Standard deviation (*SD*)	*Min, Max* (potential range)	1 BEV knowled.	2 PHEV knowled.	3 FCEV knowled.	4 BEV attitude	5 PHEV attitude	6 FCEV attitude	7 BEV adoption intention	8 PHEV adoption intention	9 FCEV adoption intention
1 BEV knowledge	4.33	1.56	1, 7 (1 to 7)	–	.82***	.68***	.21***	.21***	.34***	.25***	.26***	.32***
2 PHEV knowledge	4.17	1.63	1, 7 (1 to 7)		–	.68***	.14***	.27***	.31***	.19***	.31****	.32***
3 FCEV knowledge	3.63	1.68	1, 7 (1 to 7)			–	.13***	.13***	.37***	.17***	.19***	.41***
4 BEV attitude	4.11	1.69	1, 7 (1 to 7)				–	.54***	.14***	.73****	.37***	.12***
5 PHEV attitude	4.54	1.42	1, 7 (1 to 7)					–	.26***	.40***	.65***	.20***
6 FCEV attitude	4.96	1.41	1, 7 (1 to 7)						–	.12***	.18***	.65***
7 BEV adoption intention	3.43	1.59	1, 6 (1 to 6)							–	.60***	.38***
8 PHEV adoption intention	3.75	1.42	1, 6 (1 to 6)								–	.43***
9 FCEV adoption intention	3.87	1.49	1, 6 (1 to 6)									–

*Min = Minimum, Max = Maximum, n = 1344, *** p < .001.*

while the availability of FCEVs is restricted. Thus, the adoption intention towards FCEVs needs to be treated with caution. The measure of adoption intention of FCEVs could be attributed to an imagined scenario in which FCEVs are available and more affordable than in the current situation. Moreover, although we do not assume to find differences between subjective and objective knowledge for FCEVs (based on the results of Study 1), future research could assess the impact of objective knowledge on the adoption of FCEVs.

Fourth, it is important to note that in both studies, participants rated their knowledge, attitude and adoption intention to the different types of ZEVs in the same questionnaire. Thus, participants might have compared their answers regarding BEVs, PHEVs, and FCEVs and put them in relation to each other. In a replication, randomizing the order of the questions or implementing a (quasi-)experimental design might be valuable.

Nonetheless, the fact that we found the assumed knowledge-attitude-behaviour relationship for all three technologies also hints at the (intuitive) fact that knowledge is crucial for the adoption intention of ZEVs – independent of specific technology types, diffusion phases, or the valence of public discussions. BEVs take up a large part of the discussion on ZEVs in the media but equally receive a lot of public criticism. FCEVs take up a smaller part of the discourse but, while currently hardly available and very expensive, are often discussed in a positive light as a future replacement for current technologies. This difference in public discourse and media coverage has been studied with research approaches such as the so-called *hype cycles*, postulating an effect between increased public discussions, investments, and subsequent market development (Melton et al., 2016). The fact that EVs and FCEVs are at different phases in terms of innovation diffusion, however, does not seem to make a difference regarding the effect of knowledge on adoption intentions. This connection presents an interesting avenue for further, interdisciplinary research.

Although the results of the present studies appear stable and reliable, it might be the case that other factors are at play in the knowledge-attitude-behaviour process (see Venkatesh et al., 2003) and need to be considered as mediators or moderators of the process (Heeren et al., 2016). In a literature review, Hornik (1989) proposed five classes of variables that could impact the knowledge-behaviour relationship (structural characteristics of communities and individuals, community social influences, learned and enduring characteristics of individuals). Research showed that including one or more of these variables as mechanisms between knowledge and behaviour increased the explanatory power of the model. Thus, future research could consider, for instance, compatibility (Rogers, 2003) as mediator such as attitudes have been considered in the present study.

To conclude, the knowledge-attitude-behaviour process as well as its potential gaps might remain a controversial research topic. However, our studies showed that knowledge can impact attitudes toward ZEVs which in turn can influence the adoption intention. This was the case for different types of knowledge and also for different technical innovations in the transport sector that are in different diffusion phases. Consequently, research-based education of the general population regarding ZEVs appears to be important in accelerating the diffusion of ZEVs for a sustainable individual transport sector.

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