KNOWLEDGE MATTERS! – EXPLORING DRIVERS AND BARRIERS IN THE ACCEPTANCE OF FUEL CELL ELECTRIC VEHICLES AS A SUSTAINABLE MOBILITY SOLUTION

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Abstract: The usage of "green" hydrogen as a sustainable alternative to empower vehicles is a promising option for the strongly required reduction of CO_2-emissions in the transport sector. For the successful introduction of such new technology, user acceptance is known to be one crucial factor. The presented online survey (N = 207) investigated (1) potential barriers and drivers for the uptake of fuel cell electric vehicles (FCEVs) and (2) the effect of prior knowledge about FCEVs. Generally, respondents reported aspects connected to environmental friendliness to be main drivers and infrastructural factors (e.g., missing hydrogen stations) as main barriers connected with FCEVs independently from prior knowledge. Besides, results revealed considerable differences between participants with little vs. considerable prior knowledge implying a negative effect of less knowledge in terms of more sceptical assessments. Hence, measures enhancing knowledge about and experience with FCEVs might positively affect perceived barriers and drivers of FCEVs.

KEYWORDS: HYDROGEN VEHICLE, BARRIERS, DRIVERS, USER ACCEPTANCE, KNOWLEDGE

1. INTRODUCTION

1.1. Background

Developing and implementing suitable approaches aiming to reduce greenhouse gas emissions is decisive for the future of our society facing the considerable world's climate change problem [Fawzy et al., 2020]. In this regard, hydrogen as renewable energy source is considered one key solution to replace fossil fuels in many potential fields of application [Crabtree & Dresselshaus, 2008]. Realizing this big potential, leading industrial nations, amongst them Germany, introduced specific initiatives to develop this sustainable technology (National Hydrogen Strategy [Federal Ministry for Economic Affairs and Energy, 2020]). In this context, fuel cell electric vehicles (FCEVs) are discussed as a promising alternative for internal combustion engine cars to achieve sustainable mobility in the future, given the precondition that the vehicles are empowered with "green" hydrogen (i.e. produced using electrolyses and regenerative energy). Similar to their battery electric counterparts, FCEVs thus feature an effective solution for the reduction of CO_2-emissions in the transport sector, contributing even to decreased noise emissions, which is a big issue predominantly in cities [Cucurachi et al., 2019]. Rather than a competition between both alternative powertrains, FCEVs and battery electric vehicles (BEVs) could be seen as "complementary technologies that can mutually compensate each other's weaknesses" [Trencher, 2020, p. 2503]. FCEVs, for instance, offer the advantage of a comparably long driving range and fast refuelling times [Yue et al., 2021], which still represent the biggest barriers of BEV usage [Krems & Kreißig, 2021]. Currently, there are many developments of FCEVs focussing predominantly on technical aspects, representing essential preconditions of technological readiness, such as fuel cell durability or power density [Wang et al., 2018]. However, a successful uptake of such innovative vehicles will depend on a complex interplay of many aspects including psychological aspects such as user acceptance. Therefore, human-centred approaches are of crucial importance in the process of FCEV market launch and should be taken into account in an early stage of product and infrastructure development. Furthermore, findings from earlier research stressed the impact of knowledge about the technology (e.g., [Zaunbrecher et al., 2016]), especially during the introduction of new technology when the level of knowledge is naturally low in the general public. For this reason, the presented psychological research study seeks to gain insights into potential barriers and drivers for FCEV adoption from a user's point of view with explicit focus on the effects of prior knowledge about FCEVs.

1.2. Potential barriers and drivers in the acceptance of hydrogen and FCEVs

Acceptance and associated aspects are known to be key factors for the successful introduction of new technology, and have been even highlighted in the field of driving features and mobility (e.g., [Regan et al., 2018]; [Huijts & van Wee, 2015]), which covers the usage of FCEVs. In this context, it is important to understand potential barriers and drivers of FCEVs perceived by users in order to draw conclusions about appropriate actions or initiatives to support a successful market launch. In general, studies on user acceptance of FCEVs are rather scarce and heterogeneous [Schneider, 2017], mainly focusing on specific technologies, such as hydrogen as source of energy (e.g., [Molin, 2005]) and hydrogen refuelling stations (e.g., [Huijts & van Wee, 2015]; [Schneider, 2017]) rather than specifically FCEVs, or particular user groups, for instance experts (e.g., [Trencher & Edianto, 2021]). However, there seems to be a general tendency that potential users are predominantly positive about FCEVs and perceive them as future-oriented ([Hardman et al., 2016], [Martin et al., 2009]). Regarding potential advantages, results of consumer research highlight the environmental benefits associated with FCEVs (e.g., [Zimmer & Welke, 2012]). Providing real-life experience, [Hardman et al., 2016] reported that users perceived FCEVs to be more or less comparable to conventional vehicles with the lack of available hydrogen refuelling stations and high costs representing most important barriers. These findings of potential barriers from UK also apply to findings from other countries. In Germany, there are currently about 90 hydrogen refuelling stations [H2 Mobility, 2021], which is quite much compared to the grid of hydrogen refuelling stations in other countries but still not sufficient for a comfortably hydrogen mobility on a daily routine. Hence, it is not surprising that missing hydrogen refuelling stations are reported to be the main barriers of FCEVs across studies addressing different respondent groups (e.g., experts [Trencher & Edianto, 2021]; potential users [Schneider, 2017]). Apart from that, the actually high purchase price as well as relatively high costs for hydrogen [Trencher & Edianto, 2021] were found to be potential barriers. Considering hydrogen as an explosive gas potentially causing hazards, [Zaunbrecher et al., 2016] found mixed results when evaluating users' safety assessments of hydrogen: Participants were rather undecided with no clear ranking of hydrogen as a safe source of energy. Similar results were observed in a study by [Molin, 2005], who additionally reported effects of negatively or positively coloured information about hydrogen affecting safety assessments of hydrogen in a positive or negative direction, respectively. Conducting a representative survey and focus groups, [Zimmer & Welke, 2012] found safety concerns regarding FCEVs to be rather low with the safety of hydrogen refuelling stations being comparable to conventional ones.

To sum up, findings of earlier research reflect some potential barriers and drivers of FCEVs gained by heterogeneous methods addressing different user groups and different types of hydrogen technology. These findings served as a basis for the current study's structured and standardized investigation of assessments by potential users in Germany. As there are only few studies focusing on FCEVs rather than on hydrogen or other hydrogen applications and given the explicitly expressed need to investigate potential end users [Trencher & Edianto, 2021] in this domain, the present study contributes to enhancing research findings in the field. As psychological factors, such as prior knowledge, are known to have an impact on user acceptance when introducing new technology implying a specific relevance in the case of FCEVs, this aspect should be investigated in detail.

1.3. The role of knowledge in the assessment of FCEVs as a new technology

Most user research on hydrogen and hydrogen technology points out a currently rather low level of knowledge about hydrogen and FCEVs in the population (e.g., [Trencher & Edianto, 2021]; [Zimmer & Welke, 2012]), which may be explained by the early stage of introduction with a low number of FCEVs on the streets and an incomplete infrastructure of available refuelling stations [Schneider, 2017]. At the same time, current findings revealed predominantly positive effects of knowledge on the evaluation of hydrogen and associated technology (e.g., [Molin, 2005]). Thus, [Huijts & van Wee, 2015] found positive effects of knowledge on the acceptability of the local installation of hydrogen refuelling stations in an online study of a representative Dutch sample. Surveying potential consumers also in the Netherlands, [Molin, 2005] found strongly positive effects of knowledge about hydrogen on the willingness to use this energy source and on attitudes about hydrogen. In accordance with these findings, [Zaunbrecher et al., 2016] observed positive effects of subjective and objective knowledge, for instance in terms of higher acceptance scores, more positive attitudes and better safety ratings for hydrogen in a German sample. Furthermore, there are some hints that this positive effect of knowledge on acceptance of hydrogen refuelling stations is moderated by an enhanced level of trust in the technology [Hienuki et al., 2019]. Although current findings refer predominantly to hydrogen and hydrogen technology, it could be assumed that the aspect of prior knowledge is similarly relevant investigating FCEVs as a hydrogen technology. Furthermore, studies providing real-life experience with FCEVs, in turn leading to possibly enhanced knowledge in inexperienced user groups, showed positive effects on different facets of FCEV acceptance [Martin et al., 2009]. Summarizing the results from current research, findings imply a particular relevance of users' prior knowledge on the acceptability of FCEVs, motivating the present study.

1.4. Research questions of the study

In order to shed light on the aforementioned important aspects and research findings regarding drivers and barriers in the user acceptance of FCEVs, an online survey was conducted addressing the following research questions for a German sample:

(1) How are possible barriers and drivers of FCEVs assessed from a (potential) user perspective?

(2) Are there differences in the assessments of potential drivers and barriers concerning prior knowledge about FCEVs?

2. MATERIAL AND METHODS

2.1. Online survey and procedure

An online survey (implemented with the software Limesurvey) was conducted during March and April 2021. The invitation to take part in the study including the link to the survey was initially placed at the homepage of the professorship of cognitive psychology and human factors at Chemnitz University of Technology (CUT) and further shared via the university's mailing list for study participation as well as the mailing list of the Innovation Cluster HZwo – Drive for Saxony. The completion of all items took about 20 to 30 minutes. Amongst the respondents, who completed the survey and agreed to take part in a raffle, we drew 10 vouchers worth € 20,-. Besides, students of CUT took part in return for course credits.

2.2. Questionnaire

After obtaining informed consent, participants were asked to answer a set of closed-ended questions, starting with some items about socio-demographics, such as age, gender, education and income. After that, questions concerning mobility-associated aspects were addressed, like driving licence, mileage and the usage of car sharing, but also indications about prior experience of alternative vehicles (e.g., BEVs, FCEVs) were requested. In this regard, *mobility-specific environmental awareness* was investigated via two items according to [Bamberg & Kühnel, 1998]. Obtaining acceptable internal consistency (Cronbach's $\alpha = .652$), a sum score was calculated ranging from 1 (low *mobility-specific environmental awareness*) to 10 (high *mobility-specific environmental awareness*).

Knowledge about FCEVs was collected via three items adapted from a scale to investigate knowledge about BEVs from electric vehicle research [Neumann et al. 2010]. A mean score for *knowledge about FCEVs* (Cronbach's $\alpha = .915$) was calculated for each participant. Based on the middle of the scale of the mean score, participants were divided into two groups: (A) users with less prior knowledge ($M_{Score} < 2.5$; $n = 95$) and (B) users with more prior knowledge about FCEVs ($M_{Score} \geq 2.5$; $n = 112$). The following items for *knowledge about FCEVs* had to be answered on a 5-point Likert scale ranging from 1 (completely disagree) to 5 (completely agree):

"I am familiar with the technology of FCEVs (e.g., research, engineering activity)."
"I regularly read articles focussing on topics about FCEVs."
"Compared to an average person, I am an expert for FCEVs."

Participants were further asked to indicate their agreement to *potential barriers* and *drivers of FCEVs* on a 7-point-Likert scale ranging from 1 (completely disagree) to 7 (completely agree). Table 1 summarizes all addressed potential barriers and drivers for FCEV uptake derived from own considerations and indicated by findings from earlier research. Where applicable, the Table lists related literature and user studies for each given aspect (no exhaustive list). In order to avoid bias, we provided as many barriers as drivers for the assessment in the questionnaire.

Table 1: Items addressed for the assessment of potential drivers and barriers for FCEVs.

	Item	Literature
Drivers „I would use a FCEV, because …	…I want to reduce CO_2-emissions and save the environment."	[Hardman et al., 2016], [Zimmer & Welke, 2012]
	…hydrogen as a fuel has a good price."	
	…I already know the technology of fuel cell electric vehicles."	[Hienuki et al., 2019]; Zaunbrecher et al., 2016]
	…the usage of hydrogen improves the local air quality."	[Hujits et al., 2015]; [Hardman et al., 2016]
	…I think, that fuel cell electric vehicles are safe."	[Zaunbrecher et al. 2016], [Zimmer & Welke, 2012]
	…it would be fun to me to drive a fuel cell electric vehicle."	[Hardman et al., 2016]
	…I am interested in innovative vehicles."	[Hardman et al., 2016]
	…my mobility would be hence independently from fossil fuels."	[Hardman et al., 2016], [Zimmer & Welke, 2012]
	…it has lower noise emission than a vehicle with internal combustion engine."	[Hardman et al., 2016]
	…there is a hydrogen refuelling station next to my home."	[Schneider, 2017]
Barriers „I would not use a FCEV, because …	…at the moment there are not enough hydrogen refuelling stations."	[Hardman et al., 2016]; [Schneider, 2017]
	…hydrogen as a fuel is too expensive."	[Trencher & Edianto, 2021]
	…the usage of a fuel cell electric vehicle is a potential hazard."	[Zaunbrecher et al., 2016]; [Huijts & van Wee, 2015]
	…I do not have a glue about the functionality of a fuel cell electric vehicle."	[Hienuki et al., 2019]; [Zaunbrecher et al., 2016]
	…the production of hydrogen is not necessarily environmentally friendly."	[Hardman et al., 2016]
	… fuel cell electric vehicles are not as good as vehicles with internal combustion engine."	[Hardman et al., 2016]
	…I am afraid about potential accidents/ malfunctions."	
	…there is no hydrogen refuelling station near home."	[Hardman et al., 2016]; [Schneider et al., 2017]
	…I think that the refuelling is too cumbersome."	[Schneider, 2017]
	…the acquisition costs are too high."	[Trencher & Edianto, 2021]; [Schneider, 2017]

Note. Respondents were instructed to indicate their agreement on a 7-point Likert scale ranging from 1 (completely disagree) to 7 (completely agree). The column 'literature' summarizes related research for the respective aspects.

2.3. Sample

In sum, N = 207 participants completed the survey. Based on the mean score of the scale *knowledge about FCEVs*, the sample was post-hoc split into two sub-groups (for more information see section 2.2). Table 2 provides an overview of relevant variables describing the sample and the two knowledge groups. Looking at the characteristics of both groups, users with more knowledge about FCEVs are predominantly male, highly educated and have higher monthly income, which is quite similar to descriptions from early FCEV buyers [Hardman & Tal, 2018] and typical early adopters of new technology in general [Rogers, 2003]. The group with less prior knowledge is rather female, younger and with less monthly household income compared to the group with more knowledge. As the major part of this group holds abitur and the survey was placed in the university's context, one could assume a rather student sample in the "less knowledge" group. Almost all participants hold a driving license with less car ownership in the "less knowledge" group. Car sharing usage in both groups is rather low, while mobility-specific environmental awareness [Bamberg & Kühnel, 1998] is moderate to high. Interestingly, there are no significant differences between knowledge groups for the selfassessed mobility-specific environmental awareness. Regarding prior experience with alternative drives, about half of the participants indicated having experienced a BEV before with a bigger amount in the “more knowledge” group. In contrast, the amount of users with real-life experience of FCEVs was rather low for the whole sample with almost none respondent in the “less knowledge” group and about one quarter in the “more knowledge” group and, therefore, implying a good suitability of the applied scale for *knowledge about FCEVs*.

Table 2. Sample characteristics for the whole sample and the two knowledge groups.

Variable	**Sample**	**Group A “less knowledge“**	**Group B “more knowledge“**	**Comparison of Groups***
N	207	95	112	
Gender	34% women 66% men	59% women 41% men	13% women 87% men	
Age	*M* = 40 years *SD* = 16.9	*M* = 31 years *SD* = 14.1	*M* = 49 years *SD* = 14.5	*t*(202) = 8.99 *p* < .001 *d* = 1.26
Knowledge about FCEVs	*M* = 2.76 *SD* = 1.30	*M* = 1.55 *SD* = 0.47	*M* = 3.80 *SD* = 0.77	*t*(205) = 16.66 *p* < .001 *d* = 2.32
Education				
Secondary school	4%	2%	6%	*Z* = 5.30 *p* < .001
Abitur	33%	57%	13%	
Vocational training	12%	12%	12%	
University degree	51%	29%	69%	
Monthly income (household)				
< 1500 €	20%	32%	11%	*Z* = 4.05 *p* < .001
1500 – 3000€	18%	17%	19%	
3.001 - 4500 €	20%	18%	21%	
4501 – 6500 €	18%	13%	22%	
> 6.500 €	14%	8%	20%	
No indication	10%	12%	7%	
Driving licence	96% with licence	93% with licence	98% with licence	
Km driven/year				
> 5000	22%	42%	5%	*Z* = 4.23 *p* < .001
5000 – 10000	20%	26%	15%	
10001 – 15000	16%	12%	20%	
15001 – 20000	14%	8%	20%	
20001 – 30000	18%	11%	25%	
30001 – 40000	6%	1%	11%	
40001 – 50000	1%	0%	1%	
>50.000	3%	0%	3%	
Car ownership	72% (yes)	52% (yes)	88% (yes)	
Car sharing usage	13% (yes)	10% (yes)	16% (yes)	
Mobility-specific environmental awareness	*M* = 7.05 *SD* = 1.80	*M* = 7.26 *SD* = 1.81	*M* = 6.87 *SD* = 1.78	*t*(205) = 1.59 *p* = .113 *d* = 0.22
BEV experience	48.8% (yes)	34% (yes)	62% (yes)	
FCEV experience	13.5% (yes)	1% (yes)	24% (yes)	

Note. Sub-groups were built by the mean score for knowledge about FCEVs: Group of users with less knowledge (M_{Score} < 2.5) and group of users with more prior knowledge ($M_{Score} \geq 2.5$). *Comparison of groups was derived by calculating t-tests (for comparison of means; effect size: Cohen’s d [Cohen, 1998]) and Mann-Whitney-U-Test (for ordinal data).

3. RESULTS

Respondents' assessments of potential barriers of FCEVs revealed highest agreements for high acquisition costs, lacking hydrogen refuelling stations (in general as well as next to home) independently from knowledge about FCEVs (Fig. 1). Moderate agreements were observed for the high price for hydrogen as well as possibly non-regenerative energy has been used in the production of hydrogen showing no differences between knowledge groups. Interestingly, participants with less prior knowledge indicated significantly higher agreements that this lack of knowledge represents a barrier to FCEV uptake than persons in the higher knowledge group ($F(1, 205) = 156.81$, $p < .001$, $\eta^2 = .43$). Although agreements for the remaining potential barriers were rather low to moderate, group comparisons via ANOVA revealed significant and big effects [Cohen, 1998] with mainly higher agreements for barriers in the less knowledge group. Thus, participants with less prior knowledge about FCEVs were more concerned about too complicated refuelling procedures for FCEVs ($F(1, 205) = 23.66$, $p < .001$, $\eta^2 = .10$) and rather thought that FCEVs cannot compete with their conventional counterparts ($F(1, 205) = 156.81$, $p < .001$, $\eta^2 = .43$). For safety-associated barriers, respondents in the less knowledge group furthermore indicated higher fear of potential accidents or failures ($F(1, 205) = 47.22$, $p < .001$, $\eta^2 = .19$) as well as potential hazards due to the usage of hydrogen ($F(1, 205) = 17.61$, $p < .001$, $\eta^2 = .08$).

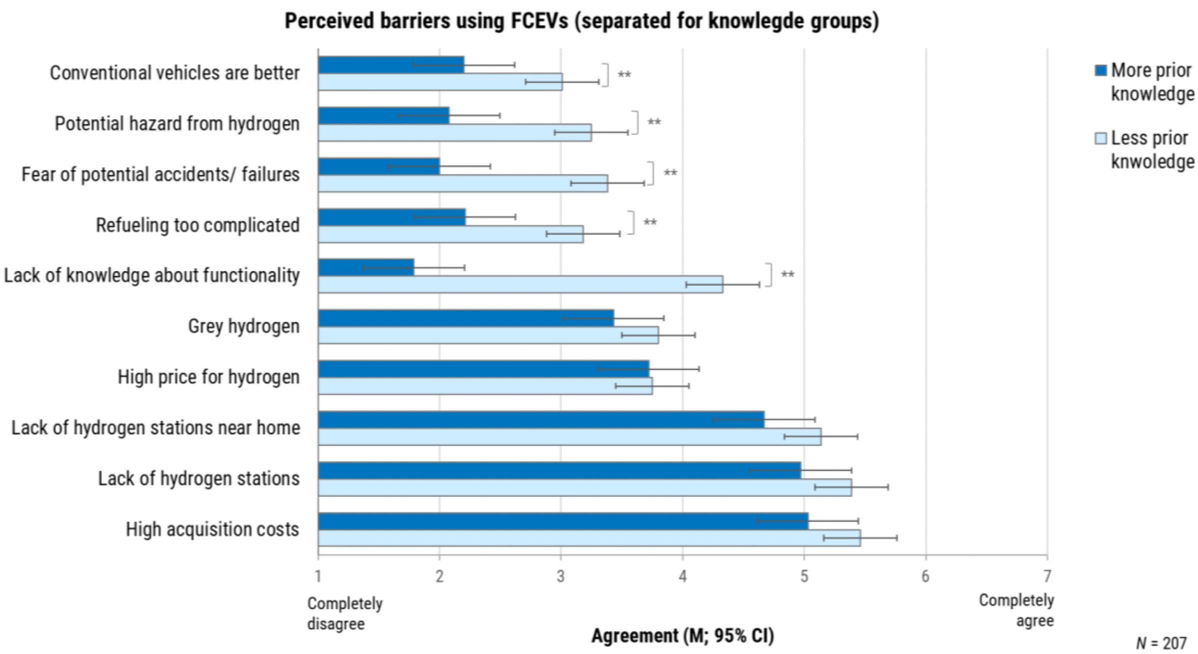

Fig. 1: Respondents' agreement to potential barriers for FCEV usage separated for knowledge groups.

Note. Bars marked with ** revealed highly significant differences between the knowledge groups ($p < .001$).

Regarding potential drivers for FCEV uptake, overall highest agreements were observed for aspects connected to the environmental benefit of FCEV (i.e., CO_2-savings, better air quality, independence from fossil fuels) regardless of knowledge group. However, factors addressing the possible advantages connected to a better driving experience with FCEVs were more positively assessed by persons with more knowledge compared to the "less knowledge" group. Thus, users with more knowledge on the one hand indicated significantly more positive ratings for driving pleasure ($F(1, 205) = 23.36$, $p < .001$, $\eta^2 = .10$) as well as for the reduced noise emissions of FCEVs ($F(1, 205) = 6.71$, $p = .010$, $\eta^2 = .03$). Similar to the assessed safety-related barriers, we observed on the other hand significantly more sceptic indications regarding safety as a driver of FCEVs in the “less knowledge” group compared to the “more knowledge” group ($F(1, 205) = 35.47$, $p < .001$, $\eta^2 = .15$). The interest in innovative vehicles was assessed significantly different for both knowledge groups, too, with significantly higher ratings in the “more knowledge” group ($F(1, 205) = 41.87$, $p < .001$, $\eta^2 = .17$). In line with the results for perceived barriers of FCEVs, we observed big and significant differences between groups regarding actual knowledge: While persons with more knowledge about FCEVs regard their knowledge as a driver, this was, of course, not the case for persons with less knowledge ($F(1, 205) = 172.21$, $p < .001$, $\eta^2 = .46$). Apart from that, persons with less knowledge rather think that the good price of hydrogen represents a driver of FCEV than the “more knowledge” group ($F(1, 205) = 14.30$, $p < .001$, $\eta^2 = .07$). Although both groups not agree that a hydrogen refuelling station next to their home serves as a driver for FCEVs, the agreement in the “more knowledge” group is significantly higher than in the “less knowledge” group ($F(1, 205) = 8.57$, $p = .004$, $\eta^2 = .04$).

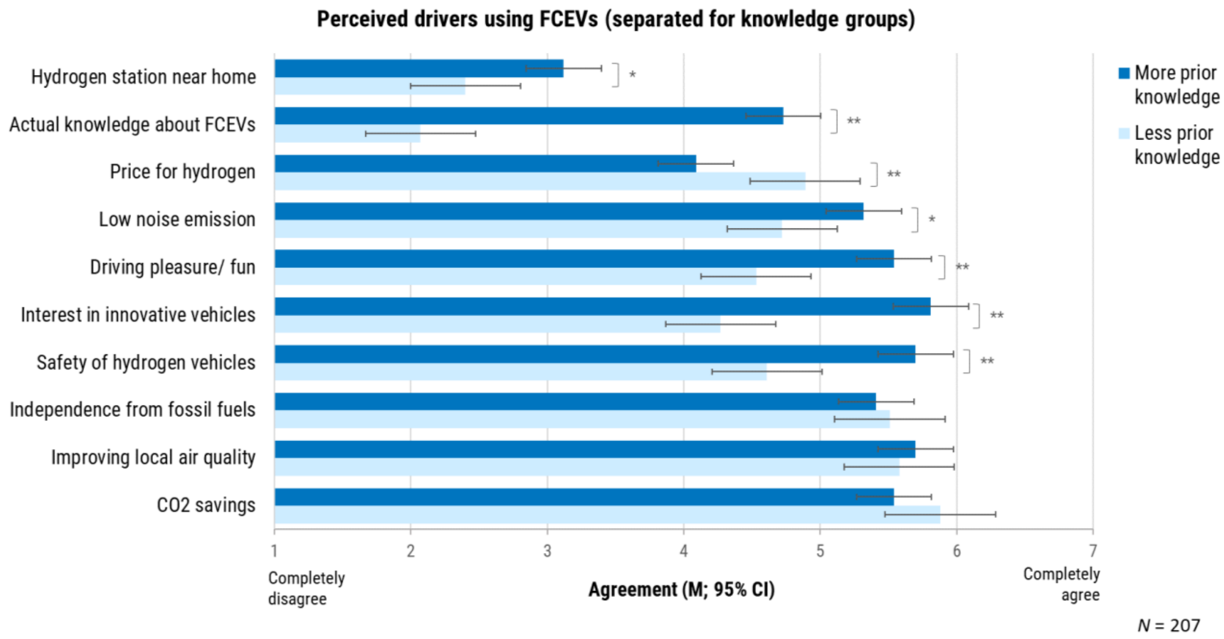

Fig. 2: Respondents' agreement to potential drivers for FCEV usage separated for knowledge groups.

Note. Bars marked with ** revealed highly significant differences between the knowledge groups ($p < .001$), bars marked with * revealed significant differences between the knowledge groups ($p < .05$).

4. DISCUSSION AND CONCLUSION

The presented study aimed to give insights about (1) users' assessments of potential barriers and drivers in the acceptance of FCEVs taking into account (2) the effect of different knowledge levels (i.e. two sub groups: less knowledge vs. more knowledge about FCEVs). Generally, results confirmed high costs and missing infrastructure as most important barriers of FCEVs ([Hardman et al., 2016]; [Trencher & Edianto, 2021]). Aspects related to environmental friendliness turned out to be biggest drivers of FCEVs from a user perspective also mentioned by others (e.g., [Zimmer & Welke, 2012]). In detail, participants regarded the reduction of CO_2-emissions, the improvement of local air quality as well as the independence from fossil fuels to be promising facets of environmental friendliness of FCEVs. For these main barriers (costs and infrastructure) and drivers (sustainability), interestingly, no differences between both knowledge groups were obtained implying that these aspects represent kind of a general knowledge level about FCEVs. Having a closer look at the advantages and disadvantages connected to the sustainability of FCEVs, it gets obvious that aspects about the environmental impact on the one hand are regarded biggest drivers, but the usage of "grey" hydrogen on the other hand does not feature a big barrier for driving FCEVs. This mixed picture implies ambivalent opinions about the relevance of environmental friendliness when it comes to FCEV usage across knowledge groups pointing in the direction of the well-known knowledge - action gap in the field of pro-environmental behaviour [Kollmuss & Agyeman, 2002]. In this regard, a study by [Hienuki et al., 2019] in the context of hydrogen refuelling stations similarly found sustainability being assessed as an advantage on a social level, which turned out to have only little impact on the acceptance of hydrogen technology on an individual level. Taken together, findings underline the importance of environmental benefits of FCEVs and at the same time highlight the need for psychological approaches to overcome the barriers for pro-environmental behaviour. Besides, a "green implementation" of this technology may help to avoid the usage of grey hydrogen.

Contrary to the similar assessments regarding main drivers and barriers in both knowledge groups, for almost all other indicated factors significantly different assessments between knowledge groups were obtained. These results extent findings from earlier research predominantly focusing on hydrogen and hydrogen refuelling stations (e.g., [Hienuki et al., 2019]) to FCEVs, further stressing the impact of knowledge on user acceptance of hydrogen technology. This considerable effect of (actual) knowledge about FCEVs is to some degree confirmed by users' ratings: Whereas respondents in the "more knowledge" group significantly stronger regard their knowledge as a driver, persons in the "less knowledge" group perceive the lacking knowledge rather as a barrier, implying kind of awareness of this issue. In sum, users with less prior knowledge were observed to assess possible drivers and barriers of FCEVs more sceptically. Less knowledge was associated with higher concerns about potential disadvantages, such as safety-related issues of hydrogen and FCEV usage. Ratings about positive aspects, like driving pleasure, innovativeness and low noise emission of FCEVs, were lower for users with less compared to users with more knowledge. Apart from that, users with less knowledge about FCEVs were rather worried than users with more knowledge about complicated refuelling procedures implying user-centred design and usability as important aspects. Findings from [Schneider, 2017], who investigated hydrogen refuelling stations with inexperienced and experienced users, revealed generally positive evaluations with some difficulties regarding the handing and some technical malfunctions during the refuelling process. Taken together with the potential concerns about the safety of hydrogen, further research should explore psychological aspects such as subjective perceptions of stress during refuelling of FCEVs as well as usability and user experience of this process. Although users' concerns about possible barriers in general are not in a critical dimension, they still reflect kind of scepticism of users with less prior knowledge (actually representing most of the public), which should be addressed by appropriate solutions where psychological approaches (e.g., in the design of human-machine-interaction) could contribute.

To conclude: What do results imply about potentially effective measures for FCEV uptake? First, initiatives should aim on strengthening potential technological drivers – most of all the sustainability of FCEVs by supporting optimal conditions as well as technical developments for the production and provision of "green" hydrogen. In addition, this green image should be further stressed, for instance via information campaigns providing insights about environmental benefits, as there are hints that also experienced users seem to lack information about details on preconditions for the sustainable potential of hydrogen [Schneider, 2017]. Next, main barriers could be addressed establishing needed infrastructure and introducing attractive incentives for buying FCEVs [Trencher & Edianto, 2021], which have been already shown to be effective measures in the case of BEVs [Liao et al., 2017]. Beyond addressing these basic barriers, sceptical assessments of users with less knowledge, such as observed for safety-related issues, could be met providing appropriate information [Molin, 2005] via dedicated campaigns. Furthermore, a user-centred design of the technology and psychologically appropriate presentation of information could contribute to a better understanding of the technology from a user perspective and enhance feelings of safety when interacting with FCEVs. To address these psychological aspects of human-machine interactions appropriately, future research should address in-depth investigations of such issues in the context of FCEVs, like for instance FCEV refueling. Not limited to, but probably most effective for strengthening driving-related advantages (e.g., reduction of noise emission), the provision of real-life experience could be effective, in turn potentially enhancing acceptance of alternative vehicles such as FCEVs [Martin et al., 2009] or BEVs [Bühler et al., 2014]. Possible implementations may be opportunities for short test drives, fleet trials or even long-term field studies offering the opportunity for everybody to get in touch with the new technology supported by psychological user research. This real-life experience might be particularly effective, given hints from user research that solely the provision of information will not necessarily lead to positive attitudes for all potential user groups [Achterberg, 2014]. Besides, usability and user-centred design are key aspects when it comes to a broader usage of FCEVs on daily routine and important preconditions for a positive first impression, especially for first-time users who are rather concerned, and therefore need to be addressed by future studies.

When interpreting the results, some limitations of the present study have to be considered. The sample of the study is not representative for the German population of potential car buyers or drivers and thus could not be generalized without restrictions. Additionally, the difference between both knowledge groups is not limited to the knowledge about FCEVs, but also observed in other socio-demographic characteristics with the higher knowledge group having similarities with the descriptions of early adopters, which are known to be different from the general public [Rogers, 2003]. However, as currently, knowledge about hydrogen technology in the public is rather scarce [Schneider, 2017], specifically persons with higher knowledge about FCEVs provide valuable insights into the area of acceptability of hydrogen technology. Furthermore, in the present study prior knowledge about FCEVs is based on subjective assessments, which might possibly to some extent differ from the objective knowledge about FCEVs. Nevertheless, several acceptance studies obtained good results investigating subjective knowledge in the context of hydrogen technology even compared to objective knowledge (e.g., [Huijts & van Wee, 2015]). In this study, knowledge groups were derived from the sample itself. Future studies should aim on an active manipulation of knowledge with a representative sample in order to examine whether similar results would be obtained for a sample representing car drivers and to get further insights in the effect of knowledge on user acceptance from a psychological perspective.

In sum, the study highlights the importance of psychological aspects in the example of the effects of prior knowledge on perceived barriers and drivers in the user acceptance of FCEVs. As the field of application of hydrogen is not restricted to the mobility sector (and even there involves more potentially modes of transport than just cars, but also trucks, busses, trains etc.), psychological user research should also take into account and contribute to further application fields of hydrogen technology (e.g., industry, logistics).

ACKNOWLEDGEMENTS

This research was part of the research project „Cognition-Based Human-Machine-Interaction“ (German: „Kognitionsbasierte Mensch-Technik-Interaktion“; Ko-MTI), funded by the German Federal Ministry of Education and Research (BMBF; grant no. 16SV8297). We thank our colleague Ferenc Rózsa providing support for implementing the online survey. Further, we thank our participants for taking part in the survey and sharing their valuable assessments and experiences. Special thanks to our colleagues from HZwo Innovation Cluster – Drive for Saxony who shared the survey amongst users with potentially more prior knowledge about FCEVs.

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