

User perceptions of the emerging hydrogen infrastructure for fuel cell electric vehicles

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Abstract

Hydrogen used to fuel vehicles can help to reduce the negative impacts of fossil fuels in the transport sector. Furthermore, fuel cell electric vehicles (FCEVs) are more energy efficient than conventional ones. FCEVs need an infrastructure of hydrogen refuelling stations (HRS). The “50 HRS Programme”, which was funded by the German Federal Ministry of Transport and Digital Infrastructure (BMVI) as part of the National Innovation Programme Hydrogen and Fuel Cells Technology (NIP), is intended to expand the HRS network and to create the basis for research and development.

This paper presents the objectives, methodology and findings of an integrated qualitative and quantitative study of user perceptions of the hydrogen infrastructure in Germany. The scientific work was part of comprehensive research activities accompanying the 50 Hydrogen Refuelling Stations Programme (financed by BMVI).

The qualitative part comprises refuelling tests at a HRS and focus groups consisting of 6 experienced and 8 inexperienced customers. In a second step, an online survey was conducted with 100 former and current users of FCEVs in Germany.

In the refuelling test, every test participant was able to successfully refuel the vehicle and the refuelling process was perceived as simple. This is supported by the survey results, which indicated that respondents were particularly appreciative of the short duration of the refuelling process (>90 % satisfaction). However, more than 80 % of the survey respondents were con-

fronted with technical problems at least once while refuelling. Overall, the technology is perceived as not yet fully market-ready and requiring improvement, especially of the refuelling infrastructure in terms of density and reliability. Despite these shortcomings, the respondents regard hydrogen as a promising future technology in the transport sector.

Introduction

Hydrogen has several benefits as a fuel for vehicles compared to petroleum: Fuel cell electric vehicles (FCEVs) run quietly, have no local emissions and although hydrogen as a fuel is not a finite resource, it can be produced using different energy sources. Furthermore, provided that the hydrogen is produced locally using renewable energy, its use in vehicles causes no greenhouse gas emissions which contribute to climate change. In addition, FCEVs are more energy efficient than conventional cars with internal combustion engines (Jacobson et al. 2015; U.S. DOE 2008).

Gaseous hydrogen is used in FCEVs to produce electricity in an onboard fuel cell, which powers an electric motor. The deployment of FCEVs is advancing worldwide: Refuelling infrastructures are being established in several countries and the activities of car manufacturers seem to confirm their commitment to fuel cell technology as a transport option (Eberle, Müller & von Helmolt 2012; Air Resources Board 2015). Recently, Original Equipment Manufacturers (OEMs) like Mercedes-Benz or BMW have launched hydrogen fuel cell prototype cars. Several car manufacturers have recently presented new hydrogen models from serial production, e.g. Toyota Mirai, Hyundai iX35 and Honda Clarity, or have announced their intention to

launch them soon, like Mercedes-Benz and Audi. Some progress has been achieved with regard to the range of hydrogen cars: By switching to the 70MPa-technology (pressure vessels) (Paster et al. 2011), a larger driving range is possible of around 400 to 800 km. Consequently, FCEVs are now being discussed as an option for longer distances, whereas battery-electric vehicles (BEVs) are considered the optimal choice for urban transport (e-mobil BW GmbH 2013).

Unlike battery-electric vehicles that can be charged to some extent using the existing electricity infrastructure (cf. the discussion around the necessity of additional charging infrastructure for BEVs, e.g. Beckers et al. 2011, Plötz et al. 2013), FCEVs need a specific and novel infrastructure of hydrogen refuelling stations. Thus, hydrogen infrastructure development is a crucial precondition to the market deployment of FCEVs. This presents several challenges for the technology including the high costs of implementing a novel network of HRSs and the high degree of technical complexity involved. Furthermore, the operating costs of HRSs are quite high as compressing hydrogen requires a considerable amount of energy (e-mobil BW GmbH 2013).

There are different funding measures in place to promote the market diffusion of FCEVs and hydrogen infrastructure in the European Union as well as in Germany. The EU Directive 2014/94/EU on the deployment of alternative fuels infrastructure (AFID) promotes the development of low-carbon transport. The directive sets out minimum requirements for the development of alternative fuels infrastructures, i.e. recharging points for electric vehicles and refuelling points for hydrogen vehicles. The actual number of HRSs is left up to each member state, i.e. there is no minimum requirement (Miguel et al. 2016), except that driveability has to be ensured by 2025.

Germany has a dedicated national hydrogen implementation plan: The National Innovation Programme Hydrogen and Fuel Cells Technology - NIP is a research, development and market preparation programme that was launched in 2006 with a first 10-year period. It is a public-private partnership with a budget of €700 m each from government and industry (€1,4 bn total). The “50 HRS Programme” is intended to expand the HRS network by funding research and development projects. The NIP will be continued within the framework of the governmental Hydrogen and Fuel Cell Technology 2016–26 programme. Besides funding research and development projects NIP is intended to speed up the process of market preparation of products based on the technology. The Clean Energy Partnership (CEP) is an initiative by industry and politics founded in 2002. As a NIP lighthouse project for the transport sector it contributes significantly to developing hydrogen infrastructure in Germany. The future roll out of HRS will be a mission driven by the H₂ MOBILITY Deutschland GmbH & Co.KG, which is an incorporated company and will plan, install and operate HRSs for fuel cell road transport applications. Until 2023, H₂ Mobility aims to have 400 HRSs in Germany (H₂ Mobility Deutschland 2016).

From a consumer's point of view, the use of hydrogen vehicles and infrastructure implies major changes: Consumers will be confronted with a new fuel and will have to adapt to a limited network of refuelling stations to start with. Basically, refuelling a FCEV is similar in several ways to refuelling a conventional car, e.g. the instruments used resemble those at

conventional refuelling stations. However, the entire refuelling process takes a few minutes longer than refuelling with gasoline or diesel. Compared to charging BEVs, however, the short time need to refuel constitutes an important advantage of the hydrogen FCEV technology. The hydrogen for FCEV is compressed to 70 MPa and has a temperature of -40 °C (SAE International 2014). While refuelling, the customer is aware of a loud hissing noise and the pump nozzle cooling down due to the low temperature of the hydrogen.

It is crucial to study user perceptions of the infrastructure in order to ensure a suitable design of the refuelling stations and refuelling network. In this paper, (first-time) user attitudes towards the hydrogen infrastructure, hydrogen refuelling stations and the refuelling procedure are analysed. The analysis is based on data from refuelling tests with experienced and first-time customers combined with focus groups (qualitative study) and survey data collected from former and current users of FCEVs in Germany (quantitative study). This work was conducted as part of the accompanying research to the “50 Hydrogen Refuelling Stations Programme”.

To begin with, information on the current situation with regard to hydrogen mobility in Germany is given and results of a literature review of the perceptions of hydrogen refuelling stations are presented. This review identified a lack of studies analysing consumer acceptance of HRSs and the refuelling procedure. Then the two empirical studies, the refuelling tests, the results of the focus groups with 14 (experienced and inexperienced) customers and the online survey with 100 current or former FCEV users, are presented. Finally, conclusions with regard to the further diffusion of hydrogen technology in the transport sector are derived.

Consumer acceptance of hydrogen infrastructure and refuelling

HYDROGEN INFRASTRUCTURE AND FCEVS IN GERMANY

In Germany, there are around 20 publicly accessible HRS in operation at the moment (CleanEnergyPartnership 2016). There are three to four HRSs in large cities such as Berlin and Hamburg, whereas other regions are much less developed. The comparison with refuelling stations for conventional vehicles (more than 14,000 (ADAC 2016)) and for compressed natural gas (CNG) vehicles (around 850 refuelling stations (Gas Vehicles Report 2015)) stresses the importance of the necessary further development of the hydrogen infrastructure.

In terms of FCEV models, the Mercedes Benz F-Cell is the most frequently used FCEV in Germany because it features in many demonstration projects. In total, 200 F-Cells have been manufactured, 90 of which are used in the CEP (CEP 2016b). The Mercedes Benz F-Cell is a prototype with a range of more than 400 km (Mercedes-Benz 2016). Since mid-2014, the Hyundai iX35 Fuel Cell has also been available in Germany for commercial users; private customers had to wait one more year. It is a small-scale production model with a range of around 600 km (Hyundai Motor Deutschland GmbH 2016b). The Toyota Mirai is said to be the first large-scale production FCEV. Its market launch in Germany was in September 2015 and its range is more than 500 km (Toyota Deutschland GmbH 2016). As of January 2016, there were 215 FCEVs registered in Germany (KBA 2016).

Hydrogen vehicles are currently more expensive than conventional cars (e.g. the Hyundai iX35 Fuel Cell costs around twice as much as the model with a diesel engine, Hyundai 2016a), in particular due to the high prices for the fuel cell, which requires platinum (Delucchi et al. 2014) and the low production volumes. Consequently, their purchase and use are supported by the German government: There is a reduced tax on fuel and a reduced motor vehicle tax as well as a subsidy of up to 4,000 euros for the purchase of a FCEV. The subsidy is funded in equal parts by the government and the manufacturer (BAFA 2016). Due to series manufacturing, FCEV sales prices will approach those of diesel-hybrid cars after 2020 (Wurster 2016).

EMPIRICAL STUDIES ON THE PERCEPTIONS OF HYDROGEN REFUELLING AND INFRASTRUCTURE

This paper aimed to include studies analysing private or commercial users' opinions with regard to hydrogen infrastructure and hydrogen refuelling procedure and a search was made of scientific databases and the internet. Only studies analysing empirical data of experienced or first-time users, i.e. individuals testing FCEV, were considered relevant for this paper.

There are relatively few empirical studies that analyse consumer opinions with regard to the HRS network and the refuelling process. Furthermore, direct comparisons of the identified studies are difficult because there is a great variety of conditions to be taken into account. For example, the countries in which these studies were conducted differ in terms of the range of models available on the market and the prices of the vehicles (e.g. due to different purchase incentives), the price of hydrogen and the available infrastructure.

No user study was identified for Germany. For this reason, findings will be supplemented by the results of two German studies analysing the opinions of non-users, i.e. the general population: Zimmer and Welke (2013) and Welke et al. (2013) carried out studies of non-users as part of the HyTrust project on the acceptance of the hydrogen technology.

Two user studies could be identified in the U.S.: Shaheen et al. (2008) surveyed users of FCEV and Martin et al. (2009) conducted hydrogen car-clinics in combination with a survey of inexperienced users. Studies that survey non-users of FCEVs on their attitudes towards the proposed installation of hydrogen refuelling stations in their neighbourhood or place of residence are not considered here (e.g. O'Garra et al. 2008 for the UK; Schmoyer et al. 2010 for the U.S.; Thesen & Langhelle 2008 and Tarigan et al. 2012 for Norway and Huijts et al. 2013 for the Netherlands). In general, the results indicate the need for more information and moderate support levels.

Perceptions of hydrogen refuelling

Shaheen et al. (2008) carried out a longitudinal study with three waves and a focus group with 65 FCEV users in a commercial context. Only drivers who used the vehicle at least once a month and who drove at least 65 km were chosen for the study. Men dominated the sample with 80 %. The participants were 44 years on average and around three quarters of them hold a bachelor's degree or higher. Six FCEV drivers took part in the focus group (four men and four persons with a university degree); four of them refuelled the vehicle themselves at least once. The authors found that the users did not have any safety

concerns while refuelling; these evaluations did not change over time (mean values between 4.13 and 4.08 on a five-point scale with five being the most positive value). The refuelling procedure was not perceived as very difficult (mean values between 2.03 and 2.1, where five indicates agreement with the statement "refuelling the F-Cell is difficult"); however, it has to be taken into account that not all participants had refuelled the vehicles themselves.

Martin et al. (2009) explored the perceptions of 182 first-time FCEV users via car-clinics. With this method, participant reactions to driving, riding and refuelling an FCEV under real-world driving conditions were evaluated. They were surveyed before and after the car-clinic. The respondents were professionally involved in the field of mobility and energy and 63 % were men. 40 % of the participants evaluated the refuelling procedure before testing the vehicle as not as safe as filling up a conventional car. After the car clinic, only 15 % still shared this opinion. Conversely, after the test, more persons (22 %) than before (8 %) felt confident that refuelling a FCEV is safer than refuelling a gasoline-powered vehicle.

Expectations with regard to hydrogen infrastructure

Martin et al. (2009) found that nearly a third of the respondents would accept a detour of 5 minutes for refuelling and 29 % state they would even drive 10 minutes to be able to refuel. This question was asked after the car-clinic.

The respondents in the study of Shaheen et al. (2008) were divided into experienced individuals who had received classes and trainings in the field of hydrogen and inexperienced individuals who had not. The survey revealed that those with experience voiced fewer concerns with regard to the limited infrastructure than inexperienced individuals. However, the concerns of first-time users decreased over time. The focus group indicated that users have concerns in terms of range anxiety due to the lack of HRSs.

For non-users, the limited hydrogen infrastructure is likewise an important issue when evaluating the technology. Zimmer and Welke (2013) conducted a representative population survey with 1,012 adults on the acceptance of FCEV and hydrogen technology. It turned out that – assuming the same price, equipment, design and make – 20 % would still not be willing to buy an FCEV. The most important reason stated by the respondents is the lack of refuelling stations (37 %). Other reasons are the low level of knowledge with regard to the technology and the opinion that conventional fuels are a proven technology. Welke et al. (2013) conducted 24 interviews and 3 focus groups with 66 customers (aged 22 to 73, 35 men, around half of them owning a car). Some participants are aware of the high costs of developing hydrogen infrastructure but still assume that this will be further expanded in the future.

DISCUSSION AND RESEARCH QUESTIONS

In summary, there are relatively few publicly available empirical studies on the user acceptance of hydrogen infrastructure and the refuelling procedure and these have been conducted under varying conditions.

In the study of Martin et al. (2009), the participants were individuals who had professional dealings with hydrogen and fuel cell technologies. This can have two possible impacts on the results: Such individuals tend to be either more critical when

evaluating the technology and its suitability for everyday use or more enthusiastic about the technology or about technological innovation in general and evaluate it more positively. Furthermore, in all user studies, the group of users is relatively homogeneous with regard to demographics, e.g. are mostly highly educated men. This group is often considered the typical “early adopter” of new technologies, e.g. electric vehicles (Plötz et al. 2014). Thus, there are no available studies analysing the views and perceptions of private customers not previously involved in the field of hydrogen. However, it is essential to include the opinions of such private users when designing the hydrogen infrastructure and HRS for the mass market.

The user studies from the U.S. were carried out some years ago in California. However, the technology has recently made rapid progress, e.g. new models from large-scale production have become available on the market and there are more refuelling stations with new HRS technologies (Air Resources Board 2015). Furthermore, hydrogen mobility in California is different from Germany, e.g. with regard to purchase incentives (CaFCP 2016a), the fact that no fuel card is needed, and the network of refuelling stations (CaFCP 2016b). As a consequence, these findings cannot simply be transferred to the current situation in Germany.

The more experiences individuals have with hydrogen mobility, the more positively they evaluate the technology and the safer it is perceived. In addition, fewer concerns are voiced with regard to the lack of infrastructure (Martin et al. 2009, Shaheen et al. 2008). This indicates that further diffusion of the technology might lead to a more positive evaluation by users. When interpreting the results of Shaheen et al. (2008), it has to be considered that not all participants refuelled the vehicles themselves.

The infrastructural deficiency is identified as the main barrier to purchasing a FCEV. This indicates the importance of further expanding the infrastructure (Zimmer & Welke (2013). A lack of infrastructure is a very plausible reason why consumers are not interested in acquiring a FCEV. This has also been demonstrated by studies analysing the motivation for purchasing CNG vehicles (e.g. Di Pascoli et al. 2001).

Methodology

The research objectives are examined in a qualitative and a quantitative study: Refuelling tests in combination with focus groups and an online survey. Two user-groups were analysed in the qualitative study: experienced and first-time customers; the survey analysed the perceptions of experienced FCEV users.

REFUELLING TESTS AND FOCUS GROUPS

Refuelling tests were conducted to analyse customer perceptions of the refuelling procedure. The tests are defined as real experiments (Burkart 2010), in which a refuelling procedure is tested in a “natural” setting. While refuelling, the participants were asked to “think aloud” (Konrad 2010), i.e. state their thoughts and feelings during the process. This is a method used to analyse learning processes, e.g. while using a new technology. The advantage of this approach is that it collects immediate feedback from the participants.

Focus groups were conducted to obtain in-depth feedback on handling the refuelling procedure. This is a qualitative ap-

proach which leaves room for feedback and spontaneous reactions from the respondents. Focus groups are structured group discussions and are especially suitable if the subject of interest is novel. The group process can encourage respondents to form an opinion and share ideas (Marshall and Rossman 1999; Morgan 1988). In order to structure the conversation, a guideline was developed to ensure that all topics of interest are covered. The guideline covered the experiences while refuelling the FCEV (refuelling experience, e.g. haptics, acoustics, perceptions with regard to safety; technical equipment and design of the HRS), and perceptions of the hydrogen technology and the network of hydrogen refuelling stations.

Two user-groups were analysed: Experienced and inexperienced customers. The experienced customers are actual or former users of FCEVs and HRSs in Germany. All of them use(d) the FCEV as a company car. They were recruited via the CEP. Inexperienced customers, i.e. potential users, were defined as persons with no experience of driving or refuelling a FCEV but with at least one car in their households. Various channels were used to recruit a heterogeneous sample of participants: personal contacts, social media, mailing lists, newspaper ads and notices posted at refuelling stations. A screening questionnaire was applied to select the participants and to ensure a heterogeneous sample in terms of demographics. The final sample consists of 14 persons: six actual or former users of hydrogen fuel cell cars and eight potential users. Seven of the respondents are female, ages range from 23 to 72 and the sample has a generally high level of education (nine individuals hold a university degree or similar qualification). Nine individuals said they were employed and four participants have at least one child in their households.

To start with, the participants refuelled a FCEV at a HRS in Berlin. They were provided with leaflets by the CEP explaining the refuelling procedure. Current users brought the FCEV they were using to the test and filled it up. All were using the Mercedes F-Cell at the time of the refuelling tests. Vehicles were provided by the CEP for the former and first-time users. Mercedes F-Cell vehicles were provided in most cases plus one Hyundai iX35.

Before the refuelling test, both user groups were supposed to complete a questionnaire. Whereas both groups were asked about prior experiences with alternative fuels, the experienced FCEV users answered additional questions on usage scenarios and usage patterns of the FCEV and demographics. The inexperienced customers were asked about their expectations with regard to refuelling an FCEV. After the refuelling tests, both customer groups completed questionnaires about the refuelling process. This approach made it possible to conduct a “before and after” comparison for the first-time users. A semantic differential with a six-point scale was used (ranging from 1 = positive evaluation, e.g. “easy” to 6 = negative evaluation, e.g. “difficult”).

Four focus groups were then carried out over four days in autumn 2015, with 2 to 4 individuals taking part in each group. The participants discussed their experiences while refuelling, evaluations of the HRS and the existing infrastructure as well as their expectations regarding further infrastructure development. The evaluations or experiences with the FCEV were also discussed. All the participants received compensation for taking part in the test and the focus group. The following figure gives an overview of the procedure.

Participants were encouraged to think aloud while refuelling and their statements were recorded as were those of the focus groups and later transcribed. The focus groups lasted between 50 and 70 minutes. The transcripts were then coded using the topics from the guideline to define a first list of codes. New codes were added to this list describing topics and aspects arising from the groups.

QUESTIONNAIRE

As a follow-up to the refuelling tests and focus group study, an online questionnaire was developed to survey, as far as possible, all the current users of FCEVs in Germany on their experiences with the hydrogen infrastructure.

The questionnaire included items on the vehicle and its use, refuelling behaviour and evaluation of the refuelling process, perceptions with regard to the hydrogen infrastructure, requirements of hydrogen production and socio-demographic data. Closed questions with predefined answer categories as well as open questions without any suggestions of possible answers were included in the questionnaire. A six-point scale was used to evaluate the technology in general (ranging from 1 = “does not apply at all” to 6 = “fully applies”). The two answers at either end of the scale were interpreted as approval or disapproval, respectively.

The link was distributed to 183 actual and former users of FCEVs via the CEP, which provided the contact details. The recipients were asked to distribute the link to other FCEV users they knew. The survey was accessible in spring 2016 and usable data sets were collected from 100 individuals (response rate: 55 %). The respondents took 17 minutes on average to complete the questionnaire.

Male respondents dominate the sample with 74 %. The age of respondents ranged between 20 and 80 with a mean age of 42 years (median age = 44 years). Respondents have a high level of education: 63 % stated they have some kind of university degree, 22 % had successfully completed the higher education entrance qualification at secondary school. 86 % of the respondents have at least one household car (apart from the FCEV).

Nearly 80 % of the respondents are current users, the rest are former users. In terms of the FCEV models, 54 % said they use a Mercedes-Benz F-Cell, and 27 % a Hyundai iX35 Fuel Cell.

Other vehicles included the Toyota Mirai and Opel HydroGen 4. Nearly 80 % of the respondents used their vehicles for commercial purposes (commercial fleet vehicles) and 16 % stated that they used their vehicle privately as well as professionally (company cars). The majority, 80 %, stated they were professionally involved in hydrogen and fuel cell technologies.

Results

The following sections present descriptive results from the survey together with the results of the qualitative study.

REFUELLING EXPERIENCE

All participants were able to successfully refuel the vehicle, even those who did not read the instructions beforehand. However, some participants asked the researchers questions while refuelling, because they were not sure about the next step. Overall, the participants took between 5 and 13 minutes to refuel a vehicle. The experienced customers were faster than first-time users due to their previous experience.

The post-questionnaire and focus groups revealed that the refuelling procedure in general was perceived as simple and not unpleasant by the majority of participants. This applies to both experienced and first-time users. From the inexperienced users' point of view, the actual refuelling experience does not differ much from the expectations expressed in the pre-questionnaire with regard to perceived simplicity and pleasure. This was confirmed by the quantitative study: The majority of users – over 90 % – were satisfied or very satisfied with the refuelling process in general. In terms of safety, the participants in the qualitative study reported no concerns, either before or while refuelling the vehicle. After the tests, the technology was perceived as even safer. Some described their feelings in the focus groups as “having respect” due to the high pressure in the system. Some of the inexperienced users said that they trust German safety standards and are therefore not concerned about safety issues.

The focus group pointed out that some first-time users were disappointed and perceived refuelling as challenging because of technical malfunctions during the tests. There were failures of the display or the start-button. Furthermore, the start of the refuelling procedure was delayed or they experienced a prema-

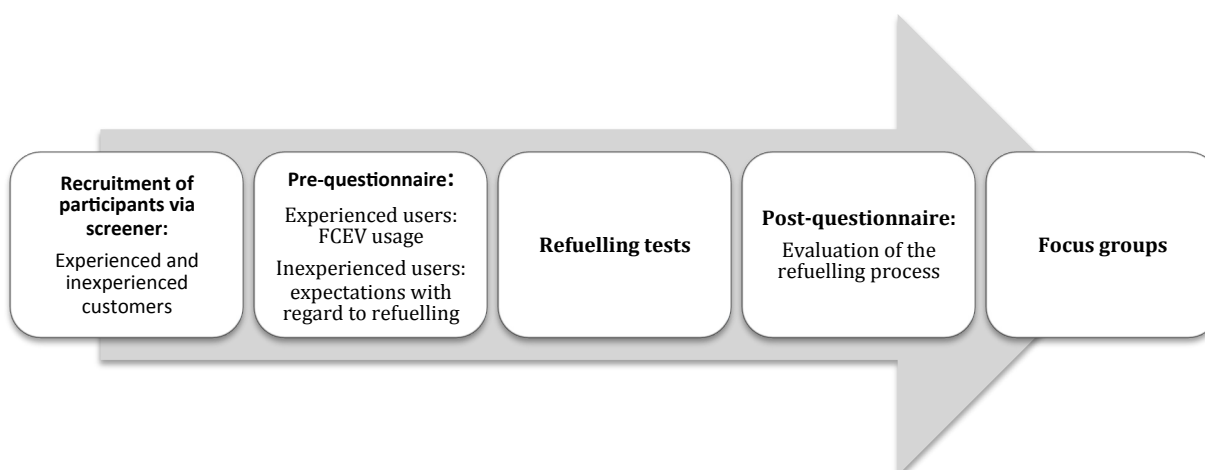


Figure 1. Procedure for qualitative empirical study.

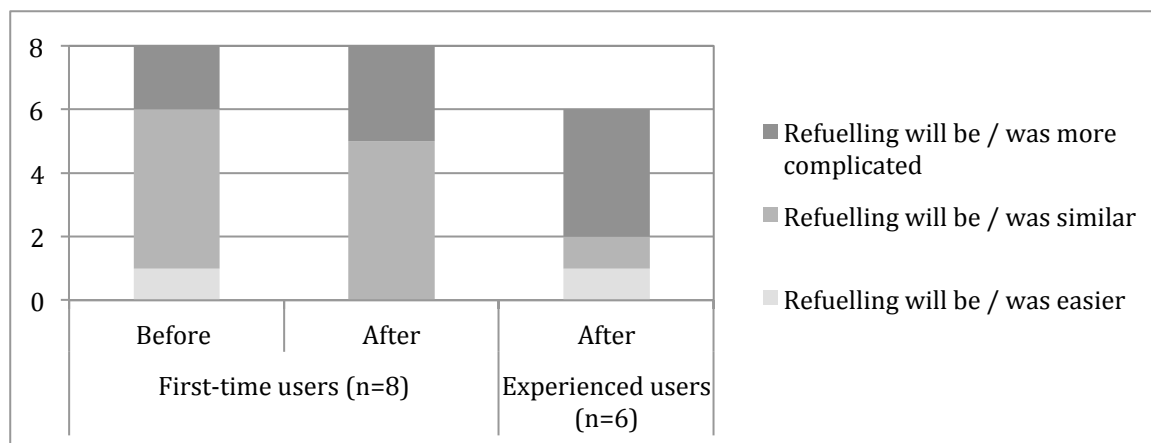


Figure 2. Comparison of conventional and hydrogen refuelling processes.

ture stop, so that the entire process had to be re-started. The technical problems led to some irritation among participants, in particular the inexperienced ones. The quantitative study revealed that more than 80 % of the users were confronted with technical problems at least once (premature stops of the refuelling process occurred most often).

Handling the pump nozzle and customer information are further aspects that need to be optimized from the perspective of first-time as well as experienced users. In the focus groups, the participants remarked that handling the pump nozzle caused difficulties due to its weight and inflexible hose. This was also stated in an open question in the user survey. In both studies, the wish was expressed for more information while refuelling.

It would be nice if it would be indicated “it starts in 10 seconds” or so. Because you were standing there, and at some point there was a loud noise and then you knew “o.k. now something is happening”. (experienced user)

When comparing gasoline or diesel with hydrogen refuelling, the majority of experienced users evaluated hydrogen refuelling as more complex in the post-questionnaire. The reasons were discussed in the focus groups: Technical malfunctions were mentioned quite often. A before and after comparison was made for the first-time users: The majority expected refuelling to be similar to the procedure for conventional vehicles. After the tests, again, most of the participants stated the process was similar, but the rest felt it was more difficult. Thus, again, the expectations are very similar to the actual experiences (Figure 2).

Despite some difficulties while refuelling, first-time users felt confident that this will become easier after several experiences and will no longer be a problem:

Yes, I also think that you will get used to it relatively quickly, maybe after three times. (first-time user)

The duration of the refuelling process was perceived very positively by users in the survey: 93 % were satisfied or very satisfied. In the qualitative study, there were clear differences between the evaluations of inexperienced and experienced users: The short duration of the refuelling process exceeded the expectations of the first-time users. In contrast, the experienced users reported mixed reactions: While some users

were satisfied with the duration, others stated that they perceived the time needed to refuel with hydrogen as rather long:

Well, I know it takes a long time ... and therefore I sit in the car and occupy myself, [...] like I read mails. Because it takes much longer than refuelling a conventional vehicle. (experienced user)

These mixed reactions with regard to the duration might also be related to the different refuelling levels of the cars used for the tests – not all the cars were completely empty.

PERCEPTIONS AND DEMANDS WITH REGARD TO HYDROGEN INFRASTRUCTURE

The focus groups revealed that both experienced and inexperienced customers favour an expansion of the hydrogen refuelling network. Current users of FCEV demanded the construction of hydrogen refuelling stations especially in central Germany to make travelling from the north to the south possible. Because of the reduced range and lack of HRS infrastructure, former and current users reported that they use(d) their FCEV only in Berlin and the surrounding area.

The survey respondents were asked whether a further expansion of the HRS network is needed. 88 % answered yes. The same question asked where further development is most urgent. Most of the respondents think that more hydrogen refuelling stations would be very useful close to business activities; but also near their place of work. One possible explanation for these findings is the fact that the vehicles are mostly used in a commercial context. Seven percent stated they did not need any more HRS (Figure 3).

To give indications about the adequate density of a future hydrogen infrastructure network, the participants were asked about their willingness to take detours in order to reach a hydrogen refuelling station. Nearly half the participants, 48 %, would drive up to 15 minutes extra per trip to be able to refuel a FCEV; 5 % are willing to drive an additional 10 minutes maximum and 10 % indicated they would take a detour of up to 5 minutes maximum. In contrast, 18 % are not willing to take any detours and the rest were unsure.

It was also asked whether and if yes how long respondents are willing to wait at a HRS before being able to start the refuelling process. 57 % stated they would wait up to 10 minutes, i.e. approx. the duration of a hydrogen refuelling process; around a

quarter would wait five minutes; 13 % would wait even longer: 15 minutes or more. The remaining respondents are not willing to wait or indicated specific conditions when they would wait like the absolute necessity to refuel.

EVALUATION OF THE HYDROGEN TECHNOLOGY

In general, the hydrogen technology was perceived positively by all the respondents in the qualitative study. They appreciated the FCEV’s quietness and zero local emissions. Current and former users reported no problems with handling the vehicle. However, some first-time users were disappointed during the trials with respect to the maturity of the technology due to the technical malfunctions. The resources used to produce the hydrogen are important for the lifecycle assessment of hydrogen mobility (e-mobil BW GmbH 2013). In the focus groups, hydrogen mobility was generally seen as an eco-friendly technology. In particular, the lack of local emissions was appreciated.

I myself have been driving the vehicle for two years now and I am really enthusiastic. It is a very eco-friendly way to drive a vehicle. (experienced user)

Some customers even perceived FCEVs to be more eco-friendly than electric vehicles. However, when questioned about this in detail, it became apparent that the majority – both inexperienced and experienced customers – are not aware of the environmental impact of FCEVs, because they do not know how hydrogen is produced in Germany. This is in contrast to the results of the quantitative study, where nearly 90 percent said they knew about the production of hydrogen. One reason for this difference might be the fact that most of the users in the survey are professionally involved in hydrogen and fuel cell technologies. Some experienced users remarked in the focus group that hydrogen production requires a lot of energy; consequently, they were more sceptical about the benefits of hydrogen mobility for the environment. However, all the customers stressed the importance of ensuring the environmental benefits of FCEVs for the further diffusion of the technology as well as the personal intention to buy a vehicle. More than 60 % of the respondents in the quantitative study stated that they wanted to use solely green hydrogen for refuelling; 53 % are willing to

pay more for green hydrogen. These respondents were asked how much more they would be willing to pay: On average, they would pay 16 % more for hydrogen from renewable energy. In the quantitative study, users were asked about their intention to purchase a FCEV in the future. 37 percent stated they were not willing to replace their currently used car by a FCEV; 9 percent said they were thinking about it. The rest were unsure or did not answer. When asked if they would consider a FCEV when purchasing their next car, 18 percent said they would; the rest said they would not or were unsure. Nonetheless, a large majority, 84 percent, stated they were interested in the further development of hydrogen vehicles (Figure 4).

The participants in the focus groups shared these opinions. The qualitative answers given make it possible to look at the reasons for not wanting to purchase a FCEV. For both user groups, the FCEV’s high purchase price, the lack of refuelling stations and technical malfunctions at HRSs are the main reasons given for not wanting to purchase a FCEV. In sum, the technology is perceived as not yet market-ready by the respondents. However, most of them regard hydrogen as a promising technology in the transport sector, because they appreciate the development of alternatives to fossil fuels.

Well I think this is definitely a promising technology (experienced user)

Some of the participants in the qualitative study see FCEVs in the near future in combination with other technologies like battery-electric vehicles, because these vehicles do not rely on the construction of a specialized refuelling station network for short driving distances. They criticized the low level of knowledge regarding hydrogen technologies in the population and proposed to increase the visibility of hydrogen mobility in the society.

Discussion

SUMMARY AND DISCUSSION OF RESULTS

First-time users’ positive expectations prior to the refuelling tests were met with regard to simplicity and level of satisfaction with the process. This is in line with the findings of Shaheen et

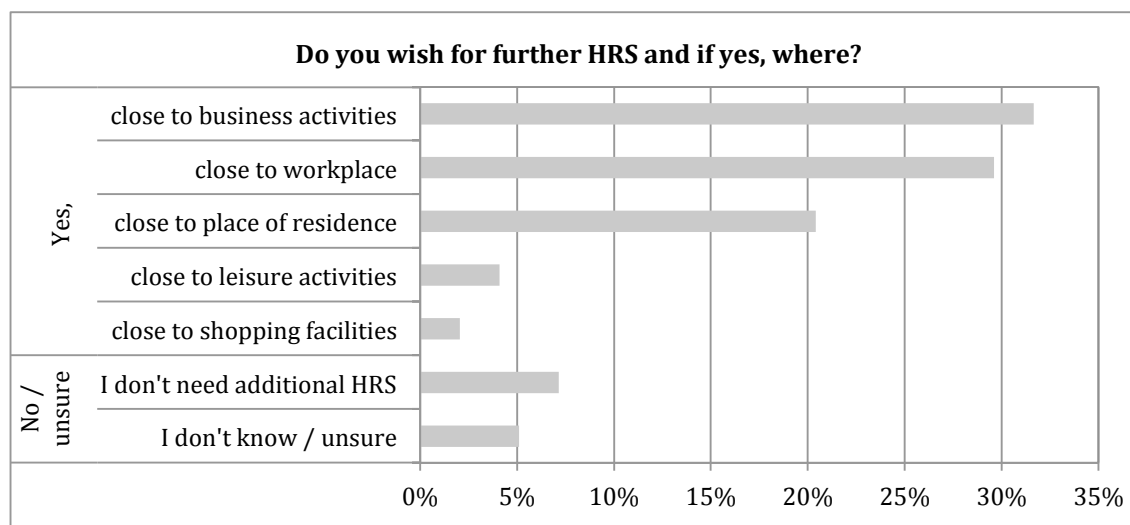


Figure 3. Demand for an expansion of the hydrogen infrastructure.

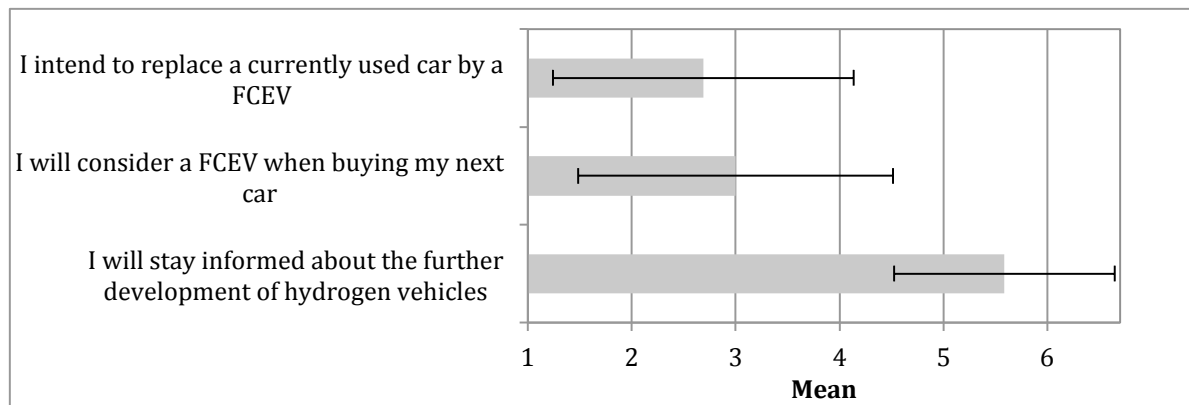


Figure 4. Intentions to purchase and use a FCEV.

al. (2008). However, the focus groups revealed that these positive expectations were marred in some cases by malfunctions at the HRSs which occurred in some of the tests. The first-time users expected the technology to be reliable, but these expectations were not met in all cases. In contrast, the experienced users seemed to be used to technical problems: They reported similar or worse problems while refuelling in the past. However, they also expressed criticisms with regard to the malfunctions and demanded that HRS become more reliable; former users, in particular, probably expected the technology to have become more reliable in the meantime.

The first-time users had no concerns with regard to safety issues and their actual experiences were even more positive. That expectations with regard to safety were exceeded is in line with the results of Martin et al. (2009). However, in the study by Martin et al., some of the customers expressed safety concerns before the tests, whereas in the study by Shaheen et al. (2008), the users did not have any concerns with regard to safety. Self-selection effects might have played a role in our study, i.e. customers with concerns about safety did not take part in the test. Furthermore, the qualitative study revealed that safety is an issue for customers and that they think about these issues; however, they did not express any serious concerns.

The respondents believe expanding the infrastructure is crucial for the further diffusion of hydrogen mobility. The fact that more than 60 % of the users demand more HRSs near locations of business activities might be caused by the belief that FCEVs are more suitable for commercial than for private use. This is confirmed by the finding that the majority have no intention to purchase a FCEV for private use. This might be explained by the fact that there are smaller variations in daily driving between different days in a commercial context, i.e. commercial fleet vehicles than in private and company cars (Gnann 2015). Furthermore, in commercial fleets additional conventional vehicles can be provided for routes where the FCEV is not adequate. Interestingly, 7 % can imagine using the FCEV with no additional HRS. In terms of the density of the hydrogen infrastructure, nearly half the participants in the quantitative study stated that they would tolerate an extra travel time of 15 minutes to find a HRS. This is in contrast to the study of Martin et al. (2009), who surveyed first-time users and found the majority is willing to take a detour of 5 to 10 minutes. One reason for this discrepancy might be the fact that actual users are already used to taking detours at present – maybe because there is no

HRS in their immediate surroundings or because their local HRS is not functioning – and are therefore more tolerant about refuelling detours.

Whereas the actual users in the survey know about hydrogen production, the test-customers stated they did not know about the environmental effects of hydrogen mobility. However, both groups perceived the technology to be eco-friendly due to the absence of local emissions. The survey respondents are willing to pay more for green hydrogen. In contrast, a German longitudinal survey with 1,407 respondents revealed that they are not willing to pay more for green electricity compared to electricity from fossil energy sources. This value decreased in comparison to the last wave (Andor et al. 2016). Thus, the early users of FCEV seem to be more tolerant with regard to higher costs for green energy than the population.

Before conclusions can be drawn from our analysis, it is necessary to point out some limitations of this study. Our results can be generalized only to a limited extent due to the fact that both the qualitative and quantitative study have relatively small sample sizes. The sample of the qualitative study is not representative of the German population in general or German car-users in particular. Moreover, self-selection effects are likely, i.e. individuals who are interested in the technology are more willing to take part in the refuelling tests than those with no interest. Thus, positive evaluations of the technology might be overrepresented in our sample. The sample of the quantitative study is not representative for all FCEV drivers in Germany as we could not find statistical data on the population of German FCEV users. Thus it is not possible to assess the extent to which the sample is representative for this population. However, this study was designed as a complete inventory count, i.e. all FCEV users were contacted, and the response rate was quite high.

Further limitations result from the fact that the inexperienced customers in the qualitative study only refuelled the vehicle but were not able to use it in daily life. Thus, they did not acquire any direct experiences with regard to the HRS infrastructure. However, they were provided with some information on the hydrogen infrastructure in the focus groups. Since the infrastructure and subsidies from the state or gas suppliers play a crucial role in the consumer acceptance of FCEVs, not all results of this study can be applied to other countries.

However, because there are only a few studies researching these issues on a detailed level and because the test custom-

ers were able to make real-world experiences with refuelling a FCEV, we assume our results do have some validity. This is underlined by the fact that most of the findings are congruent with results from the literature; but also add further details to several of these findings.

CONCLUSIONS

The purpose of this study was to acquire knowledge which could be useful when designing the future HRS network in Germany and to develop recommendations on how to support the diffusion of hydrogen mobility.

The qualitative study revealed that one important reason for the lack of interest in FCEVs is their high purchase price. It will probably be necessary to offer additional financial incentives to buy a FCEV, e.g. in the form of higher subsidies. Furthermore, communicating the achievable sales price for mass manufactured FCEVs would indicate the future accessibility of such vehicles. In addition there is a low level of knowledge about the technology in society which is probably due to the low diffusion of hydrogen vehicles and the absence of hydrogen refuelling stations. This was also confirmed by the literature (Zimmer & Welke 2013).

The qualitative study showed that acquiring direct experiences with the technology can lead to a more positive evaluation of hydrogen mobility. This was confirmed by Martin et al. (2009). An important precondition for this effect, however, is the required high reliability of the technology. Thus, for the further diffusion of the technology, it is crucial to improve its functionality.

There is a general lack of knowledge not only with regard to the technology itself but in terms of its environmental effects, which also applies to some of the users in the qualitative study. Hydrogen has an eco-friendly image in general, but some of the participants in the focus groups became more sceptical when learning about the resources currently used for producing it. Thus it is crucial to inform the public about the potential hydrogen has to contribute to a low-carbon transport sector and the storage of renewable energy.

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