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What is stored, why, and how? Mental models, knowledge, and public acceptance of hydrogen storage

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Abstract

Although electricity storage plays a decisive role for the German "Energiewende," and it has become evident that the successful diffusion of technologies is not only a question of technical feasibility but also of social acceptance, research on electricity storage technologies from a social science point of view is still scarce. This study, therefore, empirically explores laypersons' mindsets and knowledge related to storage technologies, focusing on hydrogen. While the results indicate overall supportive attitudes and trust in hydrogen storage, some misconceptions, a lack of information as well as concerns were identified which should be addressed in future communication concepts.

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Keywords: power storage; electricity supply; renewable energy; public attitude; laypersons; technology acceptance; survey; interview

1. Introduction

The energy transition towards a higher share of renewables is currently a hot topic, not only in research and development but also in the public discussion. One of the reasons for this might be the infrastructure-related features that make the energy turn visible in the landscape: wind turbines, solar panels, or new transmission lines. Those infrastructure changes modify the landscape people are used to live in into an "energy landscape" [1]. This does not go without protest, as the foundation of numerous citizen initiatives shows (e.g.,[2,3]). In this context, it has been

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shown that not all infrastructure development is associated with the energy transition to the same extent. While it is fairly obvious that new wind turbines are connected to the energy transition, this is less so for new transmission lines [4]. Similarly, storage technologies, which will play an essential role in future grids with volatile energy production based on, e.g., wind and solar power, have not yet received much attention in the public discourse. While social acceptance for power producing infrastructure like wind turbines or biomass plants has increasingly gained importance in research and development, the social acceptance of storage technology for electricity has been neglected so far. Components of the electricity grid, however, will increasingly penetrate our living environments in the foreseeable future. Therefore, it will be important to understand people's attitudes towards different types of electricity storage facilities in order to avoid local opposition with the risk of severely delaying extension of necessary infrastructure and to meet public concerns adequately with a sensibly tailored information and communication strategy.

Hydrogen is one possibility to store electricity. It is already used in the context of mobility and studies show that it is increasingly accepted [5]. It might be hypothesized, though, that people's attitudes and public perception are quite different when hydrogen is used in large-scale applications for storage, within urban environments, near city quarters, or even close to people's homes. In this context, it is also a relevant issue if public perceptions differ between different types of storage technologies (e.g., battery, flywheel generator, etc.), and how hydrogen is perceived relative to these other storage possibilities.

One major driver for the social acceptance of a novel technology is the appropriateness of people's explicit and implicit knowledge about a technology, often referred to as so-called mental models [6]. Mental models cover persons' attitudes, cognitive and affective conceptions and beliefs how a technology might work, the characteristics that are associated with it as well as possible consequences regarding implementation procedures or personal use. Mental models are not necessarily intentional and cognizant, but they work as affective, hidden drivers for the attitude for or against a technology [7]. Mental models are formed by experience and therefore often contain incomplete or even "wrong" conceptions. Uncovering mental models as drivers for acceptance is thus essential for the development of communication strategies that can be individually tailored to the specific information needs, public misconceptions, or fears [8].

In order to understand those mental models in the context of hydrogen storage in large-scale technologies an exploratory study had been conducted adopting a twofold approach, combining qualitative and quantitative methods: first, interviews are conducted with a range of laypeople to explore mental models about hydrogen storage. Second, a quantitative study is conducted in which knowledge about hydrogen storage, its perception, and its acceptance are evaluated.

2. Hydrogen storage in the context of the energy transition ("Energiewende")

The German "energy transition" and similar policies in other European countries result in a continuously increasing share of renewable power generation in the total European power generation mix. Most renewable power generation technologies are characterized by high volatility and low predictability of the power output which poses various challenges for a stable and reliable operation of the electricity grid [9]. One option to cope with these challenges is the utilization of energy storage technologies. Due to the limited geographical potential for large-scale storage plants (e.g., pumped storage, compressed air energy storage) the use of distributed mid- and small-scale energy storage systems is likely to increase in the future [10]. Examples for these distributed storage systems are batteries, flywheels, and hydrogen storage systems. While flywheels and batteries are mainly used for short-term storage, the conversion of excess electricity into hydrogen via electrolysis represents a possibility for intermediate and long-term storage. There are various technologies to subsequently store the produced hydrogen. An effective option is the direct feed-in into the natural gas grid which functions as the storage system in this case. This option, however, is limited due to the technical limitation of the hydrogen fraction in natural gas [11]. Another option is the conversion of the hydrogen to methane in a subsequent chemical process using carbon dioxide. This additional conversion allows for an unlimited feed-in of the methane into the natural gas grid, but it is also associated with significant additional conversion losses [12]. The third option is the direct storage of hydrogen in local storage systems. These include pressurized tanks, combinations of liquidation units and unpressurized tanks, and innovative storage technologies like metal hydrides [13]. Due to the high complexity of liquidation units and the status of the development of metal hydrides, pressurized tanks are currently the state of the art for distributed hydrogen storage systems. There is also the theoretical option of underground storage in geological formations, but this technology qualifies more as a large-scale energy storage system than a distributed local energy storage system [14]. Regardless of the specific storage technology, the hydrogen is reconverted to power in times of high power demand. This conversion can be performed by various systems like fuel cells, internal combustion engines, or gas turbines.

This study will focus on the public acceptance of hydrogen storage in pressurized tanks, particularly in residential areas. Because of its inherent properties, it is expected that local hydrogen storage is met with skepticism by the public.

3. Public acceptance of hydrogen

Public acceptance refers to the favorable reception and the active approval and adoption of newly introduced technical devices and systems [15]. It deals with the relation between customers, their characteristics, and different technical usage contexts and specifies both usage motives as well as barriers impeding the use and adoption of a technology.

As decentralized hydrogen storage is an option to stabilize the grid in the near future, it is essential to understand the cognitive or affective drivers of acceptance, perceived risks, and possible barriers to acceptance. Hydrogen has been extensively researched in the mobility context, e.g., public transport [16]. However, investigations into hydrogen as decentralized electricity storage option from a public perception point of view are still scarce. Studies addressing the relationship between knowledge and support for hydrogen technology have found no clear relation between knowledge and hydrogen support: more information did not automatically lead to more support. However, cultural predispositions, like trust in technology, were found to play a decisive role [17]. Even though the general attitude towards hydrogen is quite positive, perceived risks, e.g., of explosions, were still discussed frequently [18]. Research has identified the need not only for public education but for an integration of hydrogen education on all levels of training [19].

Another acceptance-relevant factor is the relation between proximity to a hydrogen storage facility and acceptance. Results in this regard are controversial – there are findings which show that proximity enhances acceptance [20] but also decreases acceptance [21] in line with the well-known NIMBY effect – but what is corroborated is that the personal attitudes underlying acceptance are not “objective” or “neutral” but rather a gut issue.

Sherry-Brennan et al. [22] investigated emotional responses to hydrogen, focusing on affect in the context of hydrogen technologies. Results show that perceptions of hydrogen were embedded in various social and technological contexts and that, although risks were also associated, they did not outweigh positive associations with hydrogen. One of the central findings is that public perception of hydrogen is characterized by different knowledge sources: “scientific knowledge, common sense knowledge, and emotion” [22]. From this it becomes clear that hydrogen acceptance comprises not only factual domain knowledge but also diffuse and subjective cognitions as well as an affective component.

4. Empirical studies on the perception of hydrogen storage

Because electricity storage technologies have not been extensively covered in the literature so far, the empirical studies were designed as exploratory studies in a two-step procedure. First, interviews with laypersons on hydrogen storage were conducted. Second, a questionnaire was developed on the basis of the interviews, in which attitudes towards hydrogen storage were assessed and compared to other types of storage technologies.

4.1. Interview study: Understanding lines of argumentation

For the interview study, ten laypeople (people who had not completed education and/or worked in a field related to storage or hydrogen technologies) were interviewed about their attitudes and knowledge about hydrogen storage.

4.1.1. Method

The interviews were conducted by a trained interviewer. The interview was structured in two parts. In the first part, participants were presented with a short information text about hydrogen storage: It contained information about hydrogen, for example, that it is a gas and highly flammable, that it is possible to generate it in a climate neutral way, and that it can be stored overground (tanks) or underground (caves). Participants were also informed that electricity can be generated from hydrogen by the use of fuel cells or gas turbines. This way, all participants had some base knowledge about the technology and could consider the possible functionality, risks, etc. of hydrogen storage. The second part of the interview consisted of questions regarding participants' ideas how hydrogen storage works and their attitudes towards it, especially if they considered it built in their immediate surroundings. Participants were voice recorded with their consent and the interviews were transcribed for data analysis. The interviews lasted between 7 and 10 minutes.

4.1.2. Sample

Five women and five men (between 16 and 80 years) participated. Eight of them worked in non-technical fields, two had a technical background. Interviewees participated voluntarily in the study and were not compensated. They were chosen from a group of interested persons based on their demographic attributes to represent a wide variety of people.

4.1.3. Results

Overall, participants did not feel very informed about hydrogen as an electricity storage technology. Some even mentioned they did not know at all that hydrogen could be used for electricity storage purposes to stabilize the grid.

General knowledge about hydrogen. Hydrogen in general was known to the majority, mainly from school experiments (oxyhydrogen reaction). One participant associated hair dye (hydrogen peroxide). They knew that it is used in cars and that it is still being researched as storage facility. Although some mentioned that it is complicated to produce, it was generally seen as positive and a "technology for the future," because it was found to be environmentally friendly.

Knowledge about hydrogen storage facility. When it came to specific characteristics of a hydrogen storage facility, its dimensions, specific elements needed and also how the hydrogen is stored, the participants showed diverse levels of knowledge. All participants knew that some kind of tank would be needed to store hydrogen, although the concepts differed greatly in detail, from "a kind of container into which the energy is stored" (female (f), 43 years) to "gas tanks." Regarding over- or underground storage, participants discussed how these options would differ with regard to necessary infrastructure and space needed:

> *"(…) directly in the neighborhood, it would not work overground because it would take up far too much space – underground would, of course, be possible, but for that you would need to make space underground, either it is already there in salt caverns or something or you would have to dig it out, but I think you wouldn't do that" (male (m), 23 years)*

For overground storage, some participants explained that infrastructural measures such as fences or buildings would be necessary so that the tanks would be protected from trespassing and other outside influences. Participants were unsure about the size of the tank, but most of them thought the tanks had to be "big," because they argued that as a gas, hydrogen has a large volume. Other participants explained that the gas was compressed or liquefied for storage. Participants were not only asked about the tank but also about other important elements of a hydrogen storage facility. Pipes were mentioned to "transport the energy" or for "gas supply," one participant mentioned "water supply," as well as facilities to "fill and empty" the tanks. Regarding the generation of electricity from hydrogen, a "burner" was mentioned, some participants explicitly referred to "fuel cells" (cf. information text). Participants also tried to make sense of hydrogen storage by referring to their knowledge about other processes or energy sources, such as natural gas, oil, or hydrogen used in cars.

Knowledge about process to store electricity using hydrogen. The knowledge was diverse when participants were asked to describe how electricity is stored and extracted using hydrogen. Some stated not to know anything at all, others provided somewhat fuzzy descriptions, and some participants gave an accurate account of the process.

> *"(…) there is a supply line of the gas, and then there is a burner, and then it is transformed to supply energy (…)" (f, 49 years)*

Perceived risks. Concerning perceived risks, the general impression was that participants were aware of explosions as possible danger but trusted the technical infrastructure and responsible technicians so that they did not see immediate danger. One participant, however, expressed an underlying fear, which, it seemed, was also influenced by media coverage. It was also evident that the fear was evoked by misinformation ("nuclear"):

> *"(...) although I would trust the engineers who built it (…), I think I would always be a little worried that something could happen (..) you're always scared when you hear that something is being built, that there is something with nuclear - (...) you would be worried (…), because you hear a lot of things that something can happen" (f, 80 years)*

Some participants said that they did not know enough to be able to judge the risks, one speculated if hydrogen would be "unhealthy for people to inhale" (m, 26 years). It was assumed by some that people would find it dangerous to store it near houses, but the danger was also put into perspective:

> *"Gas is also dangerous, but it depends on how it is monitored, I would think it is similar [to other types of gas]" (f, 49 years)*

Her argumentation was that the storage facility has to be correctly maintained and then the risks would not be as big, which was also supported by some other participants. One participant mentioned certain conditions for secure storage, such as big walls and pressure relief valves. Others feared that the gas would be able to inflame or explode (f, 16 years & f, 42 years) but concluded that, because other types of gas are already stored, also near houses, that a secure technology has already been developed. The tank should resist a certain pressure and it should also not get too hot, participants argued, otherwise it could "burst" (m, 59 years). The possible great damage that could be caused because of the "great power behind it," led one participant to conclude that hydrogen should be stored only on open fields (m, 35 years). One participant showed a more detailed knowledge about hydrogen with regard to the risks and proposed to secure the hydrogen with nitrogen, as hydrogen was only flammable in combination with oxygen (m, 28 years).

Benefits. The main benefits that were named in the interviews were sustainability and avoidance of CO_2 emissions. Therefore, hydrogen was often also called a "clean" technology. Participants also frequently mentioned that it was "climate neutral" (cf. information text). Some were not sure if burning hydrogen produced "fumes" (m, 26 years).

Conditionals. One person said that she needed more information, and that she would be interested to know how it works so she could come to her own conclusion about how dangerous it is and that this would then influence whether she would accept a hydrogen storage facility (f, 16 years). This is in line with the argumentation of another participant who explained that, if it was built in his neighborhood, he would be willing to accept it for the greater good, that he would still need to know about the risks, but that he generally trusted that it is possible to store it in a secure way (m, 23 years).

4.1.4. Conclusion

The interviews revealed that most participants had a rough idea of what a storage facility based on hydrogen would look like (mostly based on information provided in the introductory text), but hardly any of them were able to explain how hydrogen is used to store energy. While some people have at least a vague idea of how hydrogen is *generated*, almost all of them knew that it is *stored* in tanks, over- or underground. Only very few, in contrast, were able to explain how electricity is *recovered* from hydrogen. Overall, participants expressed high trust in the technology to store hydrogen, although some were skeptical with regard to storage facilities near or in residential areas.

4.2. Survey study: Quantifying attitudes and acceptance

The qualitative data were enriched and verified with a quantitative online study in which the perception of hydrogen was compared to other types of storage technologies (battery storage and flywheel).

4.2.1. Method

A questionnaire was designed which started with a part on demographics, including 6 questions on general attitude towards technology (ATT) [23], followed by a short text to provide basic information on the three types of storage technologies in focus: hydrogen, flywheel, and battery storage. The main part focused on subjective and objective knowledge (7 + 14 items), acceptance (10 items), and perception (13 items, semantic differential) of hydrogen storage.

4.2.2. Sample

182 participants took part, addressed in social networks and discussion forums on grid and energy questions. Due to incomplete questionnaires, 41 persons were excluded. After exclusion, the sample consisted of 31.2% women and 68.8% men, with a mean age of 32.9 (SD=12.5%). 70% were aged below 35, thus a young age group that was also highly educated (56 % with university degree) took part.

4.2.3. Results

Knowledge regarding hydrogen storage. Knowledge about hydrogen storage was assessed using questions regarding the subjective level of information of participants as well as a quiz. General knowledge about hydrogen storage was mixed, which is also indicated by the large standard deviations for all questions (Figure 1).

Around a quarter of participants had not heard of hydrogen storage before the survey but around half of the participants had already known about hydrogen storage before. Overall, participants did not feel very informed about hydrogen storage (M=2.8, SD=1.4) or other types of storage in general (M=3.2, SD=1.4). They were also not very well informed about the functionality of electricity storage (M=3.5, SD=1.5) or hydrogen storage in particular (M=2.8, SD=1.6), which underlines the results of the laypeople interviews (see 4.1.3).

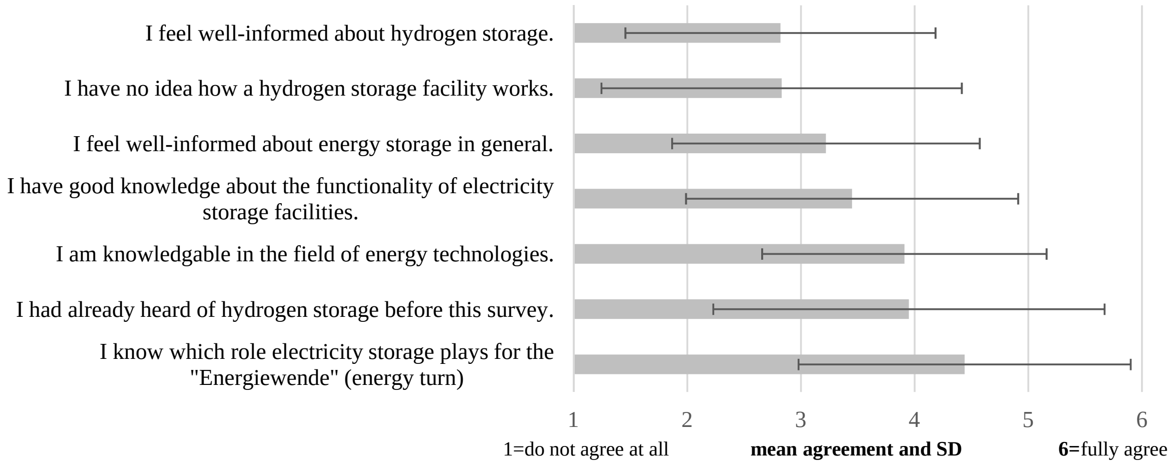

Fig. 1. Knowledge and awareness regarding electricity storage in general and hydrogen storage in particular (n= 141).

Knowledge about hydrogen was also assessed using a quiz which dealt with specific characteristics of hydrogen storage as well as potential safety issues. The quiz questions referred to information beyond those given in the information text at the beginning of the survey. Figure 2 depicts the share of correct and false answers to the quiz questions.

A maximum of 14 points could be gained in the quiz, points were awarded for each correct answer. For multiple-choice questions, one point was given for each correctly chosen answer and each dismissal of non-correct answers. The participants achieved an average of 10.3 points (min=5, max= 14, SD= 1.7). Strikingly, the questions on hydrogen storage size and siting were among those that were answered false most often, around 70% of the participants thought that hydrogen could not be stored in or near residential areas.

This is relevant especially from an acceptance and communication point of view, as it is likely that these questions are directly related to risk perception.

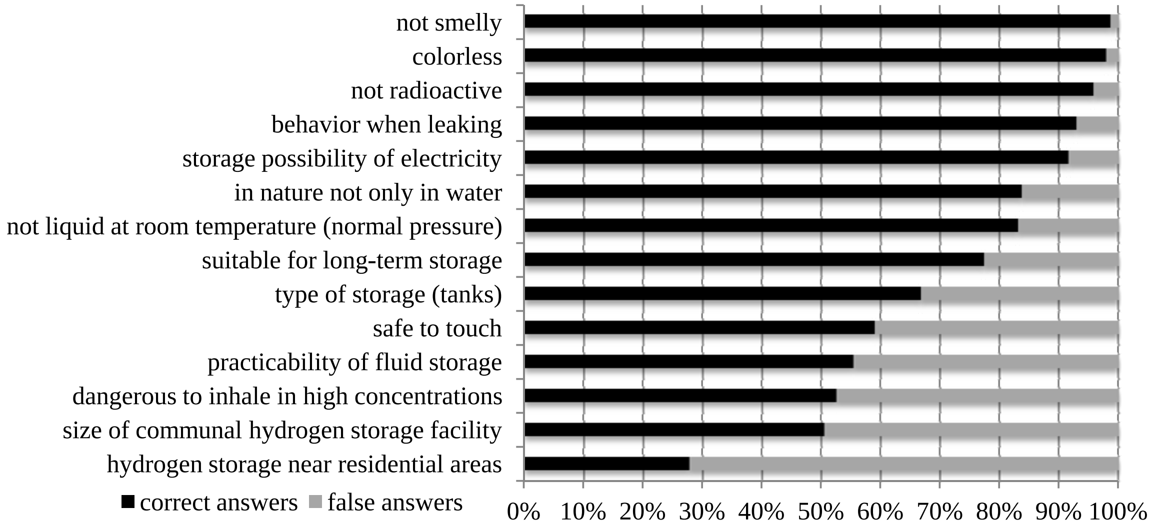

Fig. 2. Answers to quiz-questions on hydrogen (n=141).

Perception of hydrogen storage in comparison to flywheel and battery storage. A semantic differential scale [24] was used to characterize the three types of electricity storage, "hydrogen," "flywheel," and "battery," to assess possible hidden drivers for acceptance or rejection and tap into so far unexplored dimensions of storage perception. The scale consisted of two opposing adjectives (negative end=1, positive end=6), the pairs had previously been tested for suitability. Figure 3 depicts the results.

In comparison to other storage technologies, hydrogen was seen as distinctively more modern but also less mature. It was considered the cleanest of the three storage technologies, but participants were not very familiar with

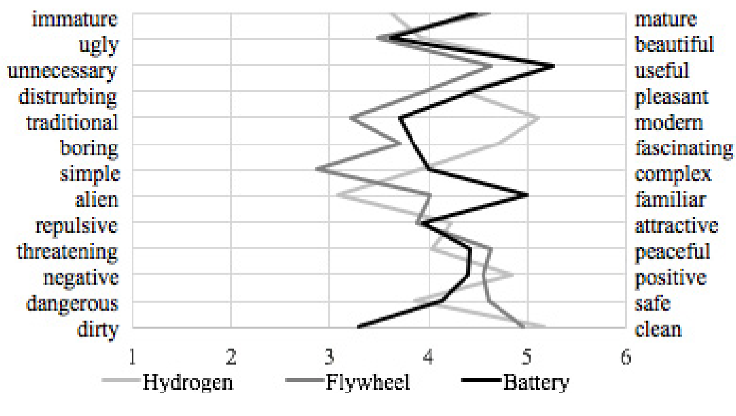

Fig. 3. Semantic differential for different types of electricity storage (n=141).

it. Interestingly, it was also the most dangerous and the most threatening alternative. Here, the trade-off between a clean and modern but at the same time potentially dangerous way of storing electricity, that was already expressed in the interviews, is underlined. When analyzing which of the emotional characteristics might be most crucial for the acceptance decision, it was found that the association of “threatening/peaceful” alone explained 13% of the acceptance (linear stepwise regression, $R^2=0.13$, $F(1,137)=20.79$, $p\leq 0.01$), showing again the affective nature of acceptance decisions.

General acceptance of hydrogen storage. Acceptance of hydrogen storage was generally high, which can be inferred from the high agreement to questions regarding local hydrogen storage and usefulness (Figure 4). However, attitudes were mixed concerning safety and storage near residential areas (Figure 5). The potential to protest, fear of health risks, and impact on landscape were considered low. In order to understand to which extent the single contributing factors explain acceptance, a regression analysis was carried out. A model with the combination of the items “willingness to protest,” “acceptance for security of supply,”and “perceived safety” was able to explain 60% of the variance of the willingness to accept hydrogen storage (linear stepwise regression, $R^2= 0.60$, $F(3,135)=67.62$, $p\leq 0.01$).

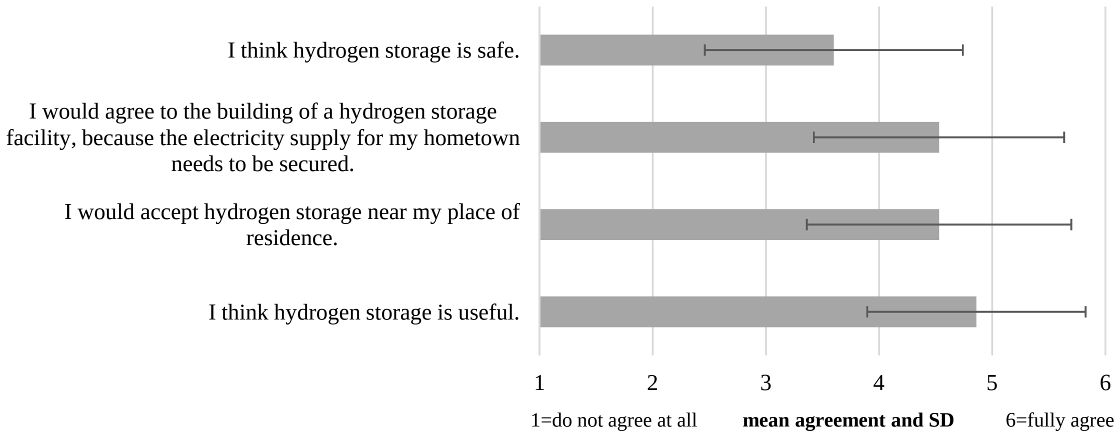

Fig. 4. Positive perceptions of hydrogen (n=139).

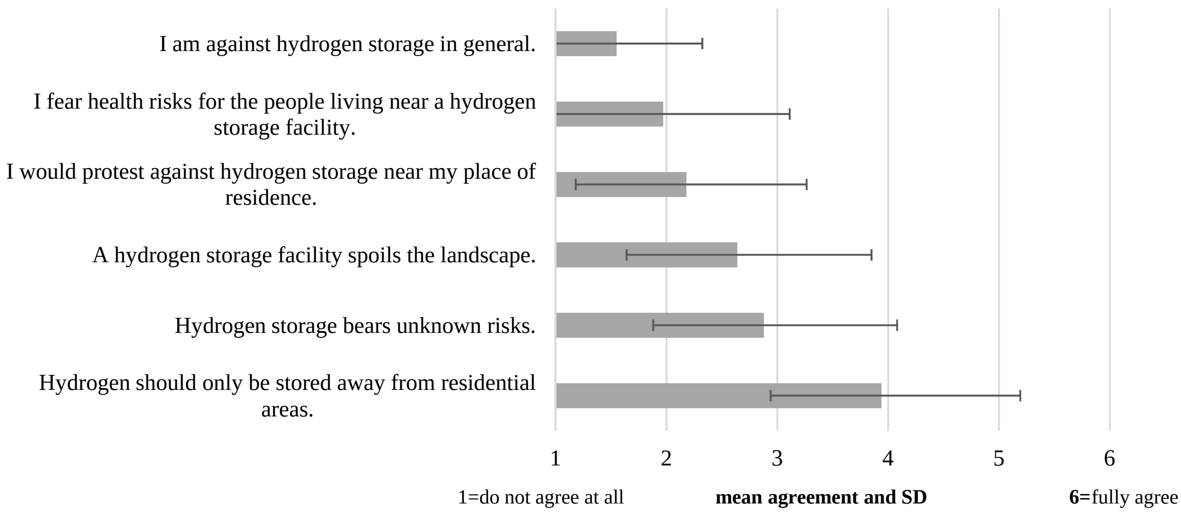

Fig. 5. Negative perceptions of hydrogen (n=139).

To investigate in how far subjective and objective knowledge as well as ATT are related to hydrogen acceptance, correlations were run (Table 1). Interestingly, it was not always knowledge (subjective or objective) that displayed the strongest correlations with acceptance issues, but ATT also played a decisive role. Furthermore, stronger relations between the feeling of being informed (subjective knowledge) and acceptance issues than for objective knowledge (quiz points) and acceptance issues were found.

Table 1. Correlations between knowledge, attitude towards technology, and H_2-stoarge acceptance *$p \leq 0.05$, **$p \leq 0.01$.

	against it in general	fear health risks	protest	spoils landscape	unknown risks	only outside residen-tial areas	safe	accept because of security of supply	accept	useful
quiz points	-.158	-.389**	-.283**	-.133	-.290**	-.067	.201*	.173*	.312**	.103
attitude towards technology	-.238**	-.209*	-.273**	-.252**	-.252**	-0.014	.240**	.186*	.320**	.255**
informed (hydrogen)	-0.115	-.387**	-.222**	-.252**	-.413**	-0.12	.243**	.256**	.225**	.190*
informed (energy storage)	-0.072	-.351**	-.195*	-.170*	-.325**	-0.047	.261**	.271**	.214*	.168*

5. Discussion and future research duties

While there is extensive evidence of a broad public rejection for local use for other energy-related technologies – such as wind parks [25] or transmission lines [26]– hydrogen storage, in contrast, seems to have an overall positive basis for social acceptance, even for local storage. According to this first study, we found respondents' general support for hydrogen, which is evaluated as "useful" and respondents are willing to agree to the building of respective facilities. However, the results have also shown that people are quite uncertain with regard to possible risks and security issues, especially when hydrogen is supposed to be stored in or near residential areas. As the sample was young and educated, care should be taken to generalize the results. Still, it is interesting to note that even among the highly educated, hydrogen storage is relatively unknown. The finding that a positive attitude towards technology was positively related to hydrogen acceptance supports the findings of [17] and [21].

Some critical remarks that referred to general fear of incidents were voiced in the interviews. This supports findings by [21], saying that general trust in science and technology has declined, which is reflected in lower overall support also for hydrogen. Risks were a major topic, in the interviews as well as the survey. This is likely due to the context of hydrogen in residential areas, although it was also prevailing in more general studies on hydrogen [17]. It is therefore concluded that risk management and an adequate communication of risks will be a major challenge for widespread diffusion of hydrogen as decentralized storage solution, which calls for a close cooperation between engineering and social sciences. Participants' opinion that hydrogen storage will not be installed near residential areas before it was safe to do so underlined the focus group results in [17], in which hydrogen was not seen as more dangerous than petrol for which safe storage solution have already been developed.

The results of the interviews and the surveys address some technical aspects of hydrogen storage systems that have to be placed into the context of the currently available technological options for hydrogen storage. The subject of "over- vs. underground storage" is directly linked to the question of the overall size of the storage [27]. Underground storage in geological formations is an option for large-scale storage systems that most likely will not be located in the vicinity of residential areas. This also applies to large-scale hydrogen liquidation and storage units.

For small- and midsized distributed hydrogen storage systems, the use of pressurized tanks is currently the preferred option. The actual size of these kind of storage systems highly depends on the available hydrogen production capacity, available reconversion technology, and other framework parameters.

The expressed concerns regarding the safety of a hydrogen storage system must be contrasted with the technical and organizational safety measures (e.g., safety valves, regular inspection) that allowed for safe and reliable operation of these systems in industrial applications in the past [28]. A comparison of the risks of the hydrogen storage technology to other storage technologies is difficult due to the different failure mechanisms of these systems (e.g., mechanical failure of a flywheel) and the different safety systems coping with these risks. The correctness of the expressed positive notion of hydrogen storage as a “clean technology” is highly dependent on the degree of renewable energy that is used for the production of the hydrogen and is not universally applicable.

It has thus become clear that there is a considerable knowledge gap in the public: Participants reported not to be well informed about hydrogen as a solution for decentralized electricity storage. Knowledge gaps were found especially for the processes before and after the storage, hydrogen generation, and electricity generation from hydrogen. On the one hand, one could argue that there is the need for public education and creating awareness regarding hydrogen generation, storage, and the overall potential of this technology for the successful and sustainable energy turn, which has also been advocated by [20]. On the other hand, it is more than naïve to believe the mere dropping of information would enhance knowledge and, as a consequence, would increase acceptance [29]. It is a sound finding that information about novel technologies does not necessarily help to fill knowledge gaps [30], does not increase acceptance in every case, and not for all citizens [16]. Those who already have a quite elaborate body of (technical) knowledge will benefit from more information, even leading to a higher support of hydrogen [16]. Those persons, however, who have a reluctant position due to fears and concerns (even if not adequate), seem to be much less receptive to more information. Their knowledge gap lies not so much in the missing (technical or procedural) information but rather in the missing trust in the technology [16,31].

In our study, we assessed both the self-reported knowledge (subjective feeling of being informed) and the factual (objective) knowledge about hydrogen and found that subjective knowledge correlated much stronger with attitudes towards hydrogen than objective knowledge. Subjective knowledge especially influenced risk perception. This indicates a call for research on the differentiation between objective and subjective knowledge (in order to understand the sources of knowledge-related acceptance). Furthermore, novel forms of public information strategies need to be developed. This includes, for example, another information policy. Rather than to overload citizens with information that is neither needed nor wanted, it seems to be more useful to first ask the public in which way, about what, and also when they need to be informed [29]. This would help to specifically control and organize the information knowledge process. As hydrogen technology might be too abstract and difficult to assess for laypeople, as it is not part of their everyday reality [22], another way could be to give the public some hands-on experience, the chance to get in contact with the novel technology using demonstrators, living labs, or even playful public participation [32]. By this, information would also be delivered, but, at the same time, people with strong concerns are given the chance to gain experience which might also help to increase trust.

6. Conclusion

In general, participants in both studies expressed trust towards hydrogen storage. However, fear of risks, especially regarding hydrogen storage in residential areas, should be addressed adequately. In comparison to flywheel and battery storage, perception of hydrogen was more positive. Future studies should also focus on exploring the public knowledge about differentiation between long- and short-term storage, as the laypeople interviewed did not seem to be aware of the differences. Furthermore, research on storage alternatives to hydrogen in tanks in residential areas could be useful, e.g., metal hydride storage, as this could reduce the fear of exploding gas tanks. Overall, a need for adequate communication concepts on hydrogen as a decentralized electricity storage solution was identified.

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