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RESEARCH

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# Social acceptance of green hydrogen in Germany: building trust through responsible innovation

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## Abstract

**Background** Social acceptance presents a major challenge for Germany's transition to green energy. As a power-to-x technology, green hydrogen is set to become a key component of a future sustainable energy system. With a view to averting conflicts like those surrounding wind energy, we have investigated social acceptance of green hydrogen at an early stage in its implementation, before wider rollout. Our study uses a mixed-method approach, wherein semi-structured interviews ($n=24$) and two participatory workshops ($n=51$) in a selected region in central Germany serve alongside a representative survey ($n=2054$) as the basis for both understanding social attitudes and reaching generalisable conclusions.

**Results** Overall, it is possible to observe both a marked lack of knowledge and a large degree of openness towards green hydrogen and its local use, along with high expectations regarding environmental and climate protection. We reach three key conclusions. First, acceptance of green hydrogen relies on trust in science, government, the media, and institutions that uphold distributive justice, with consideration for regional values playing a vital role in establishing said trust. Second, methodologically sound participatory processes can promote acceptance, and active support in particular. Third, recurrent positive participatory experiences can effectively foster trust.

**Conclusions** Accordingly, we argue that trust should be strengthened on a structural level, and that green hydrogen acceptance should be understood as a matter of responsible innovation. As the first empirical investigation into social acceptance of green hydrogen, and by conceptually interlinking acceptance research and responsible innovation, this study constitutes an important contribution to existing research.

**Keywords** Green hydrogen, Social acceptance, Responsible innovation, Participation, Trust

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## Background

To achieve greenhouse gas neutrality by 2050 and honour the Paris Agreement as well as to implement the sustainable development goals (SDGs), Germany needs renewable energy sources to form the cornerstone of an environmentally friendly and sustainable energy supply system [1]. The government's „National Hydrogen Strategy" [2] accordingly identifies green hydrogen, which is produced via electrolysis powered by renewable electricity, as a key component of such a system. On a European level too [3], the potential of green hydrogen to play a key role in the European Green Deal for the European Union

[4] has been recognized [5]. However, development and above all implementation of this technology are still at an early stage. The resulting lack of practical experience with it, especially among the general public, makes studying social acceptance of green hydrogen challenging [6]. Yet therein also lies a valuable opportunity: the earlier relevant acceptance factors can be identified, the more effectively long-term, sustainable solutions can be developed, ensuring wide social adoption and use across various industries.

As initial explorations of power-to-x technologies emphasise, participation has an important role to play in this regard [6, 7]. In the debate surrounding renewable energy infrastructures, this is by no means a novel insight: participation has been considered key to Germany's transition to green energy for a number of years [cf. [8]]. Creating opportunities for public involvement can help resolve or mitigate potential conflicts arising from the creation of renewable energy facilities, for instance, when selecting locations for wind farms. Moreover, openness and transparency increase the legitimacy of planning and decision-making processes—regardless of their actual outcomes. Social acceptance is thus not solely dependent on the properties of a given technology, but is likewise influenced by interaction and dialogue among various stakeholders.

This study, therefore, focusses on the role of participation in green hydrogen acceptance. The aim is to show how, as a matter of responsible innovation, participation can promote trust and lay a sustainable foundation for social acceptance of green hydrogen. Working from the assumption that trust is crucial for social acceptance, and that participation should, therefore, aim to promote trust, we ask the following research question: can participation promote social acceptance of green hydrogen—and if so, how?

To answer this question, we chose a mixed-method approach, combining a representative survey of the German population ($n=2054$)—designed to both gauge green hydrogen acceptance and test six hypotheses on the relationship between acceptance, trust and participation—with findings derived from qualitative interviews ($n=24$) and two participatory workshops ($n=51$) conducted as part of a case study carried out in and around Leipzig [9]. The survey results were subjected to quantitative analysis for the sake of drawing reliable and representative conclusions while also representatively validating the qualitative findings from our case study. Conversely, our case study findings facilitate a better understanding of the relationships confirmed by our quantitative survey.

This paper is structured as follows. In the next Sect. "Green hydrogen, social acceptance, and responsible innovation", we define our research question against the background of the current state of research on the connection between participation and social acceptance of sustainable energy system transformation. After that, we present our quantitative "Quantitative data" and qualitative "Qualitative data" findings, which are then discussed in terms of the relationship between participation, trust and green hydrogen acceptance "Discussion". Finally, we point out important implications "General implications" and limitations of the study, and suggest avenues for further research "Limitations and avenues for further research".

## Green hydrogen, social acceptance, and responsible innovation

Green hydrogen has the potential to become a cornerstone of the global transition to green energy [10–12]. First, converting renewable electricity to green hydrogen makes it possible to store weather-dependent regenerative energy derived from wind and sunlight [13–15]. Second, hydrogen-powered fuel cells and hydrogen-based synthetic fuel constitute possible alternatives to direct electricity usage and battery-powered technologies in transport [16, 17] and heating [18]. Furthermore, in areas such as the steel and chemical industry, green hydrogen technology provides the only route to decarbonisation [19, 20]. At the same time, green hydrogen's potential role in Germany's energy transition is a matter of not only technical feasibility, but also socially accepted implementation [21]. This becomes all the more important as the resource-intensive construction of infrastructure requires decisions with long-term impact, although some existing infrastructures, such as natural gas pipelines, may also be used for hydrogen.

### Social acceptance of renewable energy innovation and the role of participation

Although the majority of Germany's population has a fundamentally positive attitude towards the country's energy transition, conflicts regularly arise during the planning and implementation phases of specific projects. The „social gap" [22, 23] between strong approval voiced in opinion polls on one hand, and local protests on the other, shows that social acceptance takes place on different levels [24]. Public reaction to new energy environments is thus not just predicated on aspects of the technologies themselves, such as potential safety issues. Local context and the ways in which people are personally affected likewise influence their perception and assessment of changes to their everyday surroundings [25, 26].

In the past, public rejection was often seen as symptomatic of the NIMBY ("not in my backyard") syndrome,

yet this simplified view is now considered outdated [27–29]. Current approaches suggest that local changes can just as easily elicit positive reactions „in situations of good 'fit' between symbolic meanings associated with both place and project" [30], with local context and the community's day-to-day life providing possible symbolic, emotional and ideational points of reference [31, 32]. This also pertains to the relationships between the stakeholders of a given project. In particular, the presence or absence of a sense of trust and fairness among stakeholders helps determine the public's reaction to new energy technologies [33]. Accordingly, in both research and practice, the question of how increased participation can promote renewable energy acceptance has become increasingly relevant [8, 34].

In contrast to renewable energy technologies, such as wind and solar power, green hydrogen is still largely unknown to the majority of the German population [35–37]. To date, only a small number of public participation projects and focus group studies have examined the German public's attitude towards hydrogen technologies in general. In addition to sparse knowledge and a lack of direct experience, these studies reveal a fundamental openness that could turn into either approval or rejection, depending on, e.g., project-related factors [38], the information made available and the dynamics of communication [39, 40]—as well as doubts as to whether hydrogen technologies are being developed and used to serve the common good, and not just business interests [36, 41]. Research carried out in the United Kingdom and the Netherlands reveal similar findings, identifying distrust of industry and public institutions as a significant barrier to acceptance [42–44]. Against this background, we maintain that social acceptance of green hydrogen should be investigated at a very early stage in its implementation, with a particular focus on the role of trust.

### Linking social acceptance with the concept of responsible innovation

The concept of responsible innovation centres on the development of new technologies in harmony with social values [45–49]. The corresponding academic field comprises not only conceptual and empirical research, but also the development of practical approaches, including methods and tools that help shape processes, organisations or the innovation system as a whole [50, 51]. Responsible innovation aims not just to avoid ethically, socially and ecologically undesirable consequences, but also to address specific societal challenges through innovations that contribute to the common good. Operating within a participatory governance framework, innovation processes should accordingly involve not only directly responsible organisations, but also more broadly affected societal actors, society at large, or individual members of the public [52]. The underlying premise is that early integration of a variety of stakeholders makes it possible to incorporate multiple perspectives—and thus also social values—into the development of new technologies. In a process thus marked by inclusion and responsiveness, existing dynamics between actors within the innovation system can change and new relationships be forged, while a greater degree of democratisation helps establish mutual trust among civil society, science, business and government [45, 53].

Despite being concerned with the development and implementation of new technologies in line with social values and for the benefit of society—a process in which participation plays a central role—the concept of responsible innovation has, to date, not been systematically linked with acceptance research. Within acceptance research, on the other hand, explicit connections have been drawn to responsible innovation, most prominently by Pellizzone et al. [54, 55]. Were the two fields systematically interlinked, it could help uncover their respective blind spots and open the door to mutual learning and synergy. While acceptance research often assumes a passive view of its subjects in the face of a given technology, responsible innovation, though methodologically often less refined, is based on the concept of the constructive shaping of a technology with the aim of making it socially desirable and acceptable. The fact that possible synergies have not yet been explored more extensively is all the more surprising given that the concept of responsible innovation has been incorporated into research on the global transition to green energy [56, 57], and considering that acceptance has always been considered a (side-) effect or even one of the aims of responsible innovation [52, 58].

We suspect that there are two reasons for this. First, the focus of acceptance research falls primarily on individuals, groups, communities or entire societies as (potential) end users or as (potentially) affected by a given technology. The technology itself, however, is viewed from a passive, external perspective as an object of acceptance that is essentially taken as given [26]. Responsible innovation, on the other hand, focusses on the circumstances and process surrounding the development of the technology in question, with the aim of substantially influencing said process and altering its outcome in response to societal needs. Second, responsible innovation aims to effect systemic change, its medium-to-long-term goal being the democratisation of innovation via sustainably changed relationships between different actors [52, 59, 60]. By contrast, acceptance research mainly focusses on specific use cases, the end goal being the successful introduction

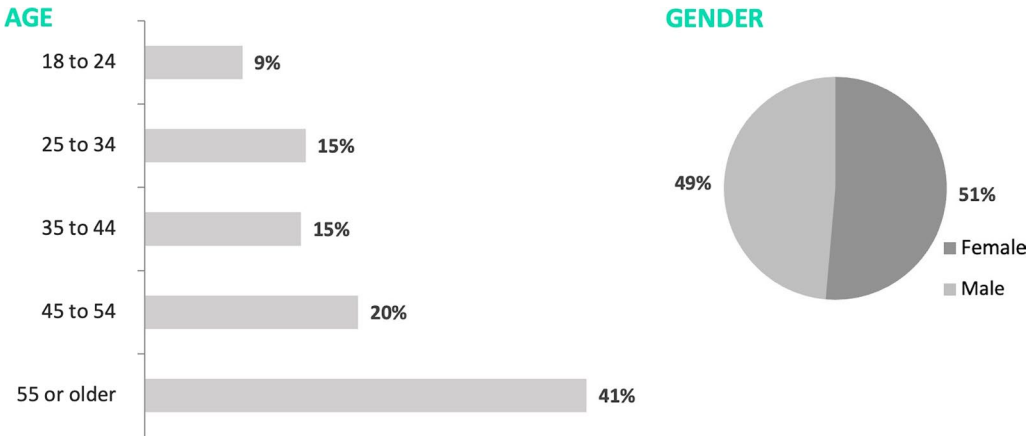


**Fig. 1** Structure of the quantitative data sample by age groups and gender

and sustainable local or general adoption—i.e., acceptance—of a given technology.

This paper constitutes an argument for more decisively and systematically interlinking these two fields of research and practice. Using the example of green hydrogen, we aim to show how this can benefit the investigation and promotion of social acceptance from the perspective of responsible innovation.

## Quantitative data

### Methods

An approximately representative survey was conducted between 15 and 25 May 2020, in the form of an online questionnaire completed by a total of 2054 respondents. The results of the survey were weighted and are representative of the German population aged 18 and above (Fig. 1). The standardised German-language questionnaire was developed by the authors of this paper, and the fieldwork carried out by an external contractor. The contractor ensured the representativeness of the sample by specifically approaching suitable participants. The contractor conducted the survey online using a method called Active Sampling. When using Active Sampling, restrictions are put in place to ensure that only the people contacted are allowed to participate. This means that all the respondents who completed the survey have been selected, regarding the representative composition of the following criteria: sex, age, net household income, home ownership, federal state, education, children under 18, last election decision, migration, religion, professional activity.

#### *Description of questionnaire and variables*

The questionnaire consisted of 97 questions grouped into 27 sets. In addition to general demographic questions regarding age, place of residence, marital status, income, household size and political orientation, respondents were given questions related to green hydrogen acceptance. Environmental awareness was assessed via 23 questions and—as in the federal government's most recent study on environmental awareness in Germany [61]—mean values were subsequently calculated to, respectively, represent cognitive environmental awareness, emotional environmental awareness, and environmentally conscious behaviour on a scale of zero to ten. Further questions focussed on experiences with participatory processes and the perceived competence and trustworthiness of a variety of actors from the fields of government (comprising both local and national government, as well as European institutions), the media (comprising print media as well as public and private broadcasting), research and education (comprising research facilities and academic institutions), business (comprising small and large-scale enterprises) and respondents' own private sphere. Additional factors assessed via the questionnaire include respondents' perceived self-efficacy, their willingness to become involved in promoting or opposing renewable energy use in their own city or municipality, their familiarity with hydrogen in general and green hydrogen in particular, what impact they expect green hydrogen to have on areas, such as safety, mobility and environmental protection, and the importance they attach to public involvement in green hydrogen adoption. The scales used are explained in more detail in Sect. "Results" below.

#### *Statistical analysis*

In line with our research question, the following statistical methods were employed in analysing the survey data. In an initial analysis, linear regression was used to determine the factors that influence local approval of green hydrogen. Effect size was calculated following Cohen

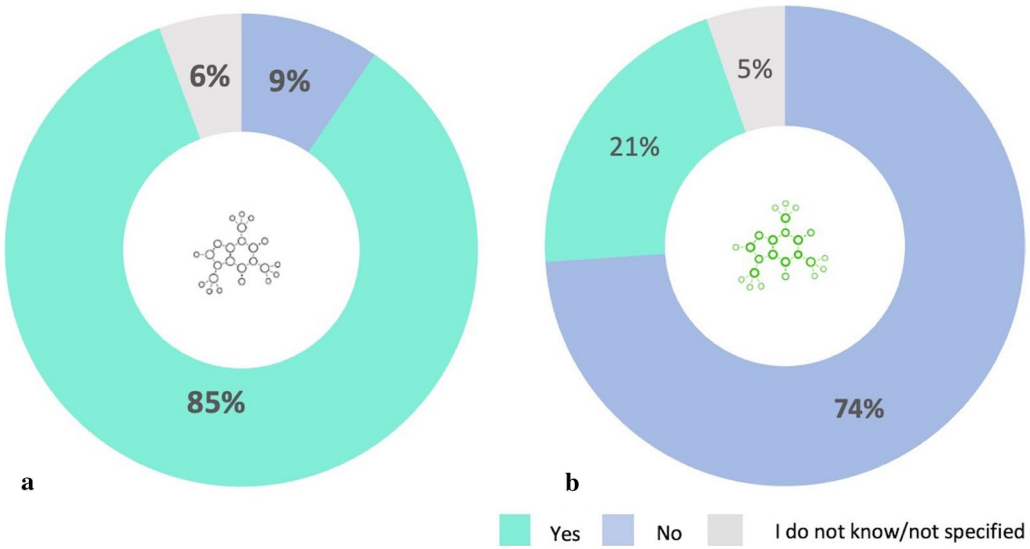


**Fig. 2** **a** General familiarity with hydrogen among the German population. **b** General familiarity with green hydrogen among the German population

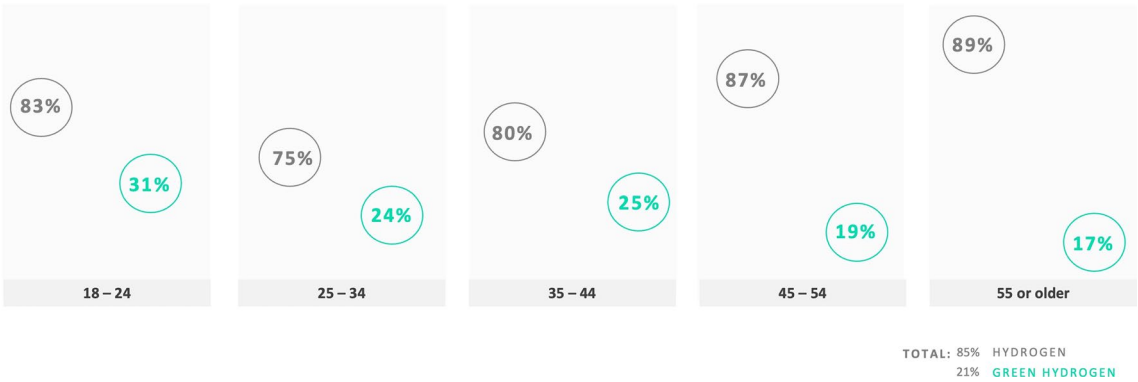


**Fig. 3** Differences in general familiarity with hydrogen and green hydrogen among the German population by age group

[62]. Due to its exploratory nature, this initial stage of the analysis encompassed numerous independent variables. Given the variables' level of measurement and partial lack of normal distribution, a Spearman rank correlation was subsequently carried out [63]. Differences between groups were then analysed using the nonparametric Wilcoxon test, since the variables did not satisfy the assumption of normality [64]. In the case of multiple tests, Bonferroni correction was used to counteract alpha error accumulation [65].

## Results

### Descriptive findings on green hydrogen acceptance in Germany

While 85% of respondents indicate having heard of hydrogen, the same is true for only 26% in the case of green hydrogen (Fig. 2). Here, significant differences can be observed between age groups: older individuals are more familiar with hydrogen as such, whereas younger people are more likely to have heard of green hydrogen (Fig. 3). Familiarity with (green) hydrogen is also seen to differ significantly in accordance with level of education, with those in possession of or currently studying towards a university degree or equivalent qualification being more likely to have some knowledge of it (Fig. 4). No significant regional differences can be observed in this respect.

Among respondents, the most well-known use of hydrogen is within the field of mobility (as indicated by 70%), followed by the energy supply sector (56%) and industrial settings (48%). Only 37% of respondents feel able to form an opinion of hydrogen technologies, in contrast to other energy technologies, such as solar (62%) and wind power (60%). 64% of respondents expect green hydrogen to have a positive impact on environmental

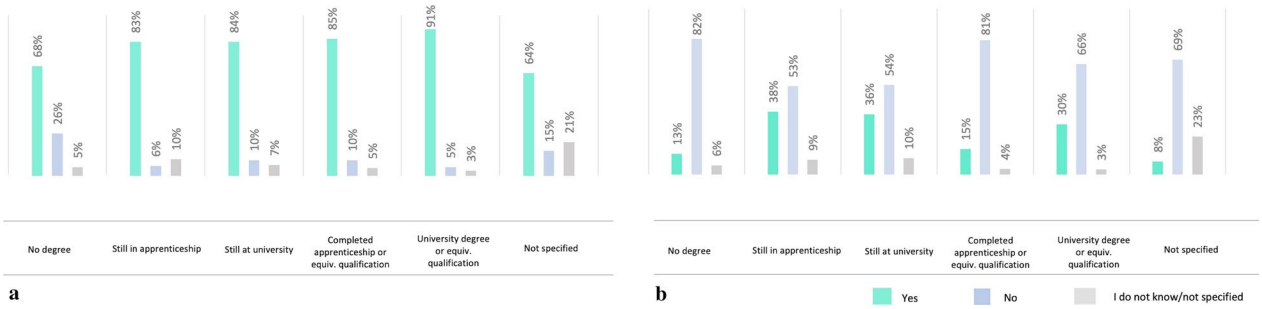


**Fig. 4** **a** Differences in general familiarity with hydrogen by level of education. **b** Differences in general familiarity with green hydrogen by level of education

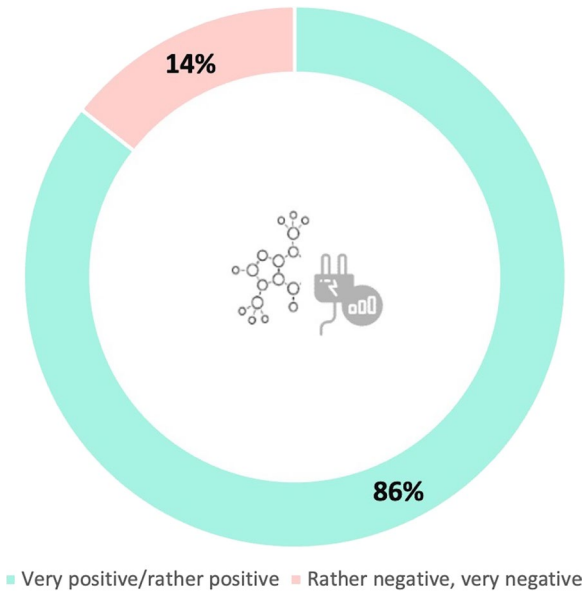


**Fig. 5** Positive or negative local approval of green hydrogen among German population

protection and sustainability, followed by mobility and infrastructure (52%), regional value creation (43%), and job creation and structural change (40%). Only 7% of respondents expect green hydrogen to have a negative impact on public and personal safety, whereas 60% foresee no or even a positive impact, and 33% declined to comment. Here, it is worth noting that 87% of undecided respondents, along with 61% of those who foresee a negative impact on safety, nonetheless have a very or somewhat positive attitude towards local green hydrogen use.

86% of respondents indicate feeling very or somewhat positive about green hydrogen usage in their own cities or municipalities (Fig. 5). Whereas 43% of those in favour are very or somewhat willing to become actively involved in promoting local adoption of green hydrogen, only 13% of those opposed indicate a willingness for active involvement (Fig. 6). Furthermore, knowledge is seen to have a highly significant influence on approval—92% of respondents familiar with green hydrogen approve of its use in their local environment, as opposed to 85% of those unfamiliar with it—and an even clearer impact


**Fig. 6** Local active support for and active opposition to green hydrogen in comparison with renewable energies in general among the German population

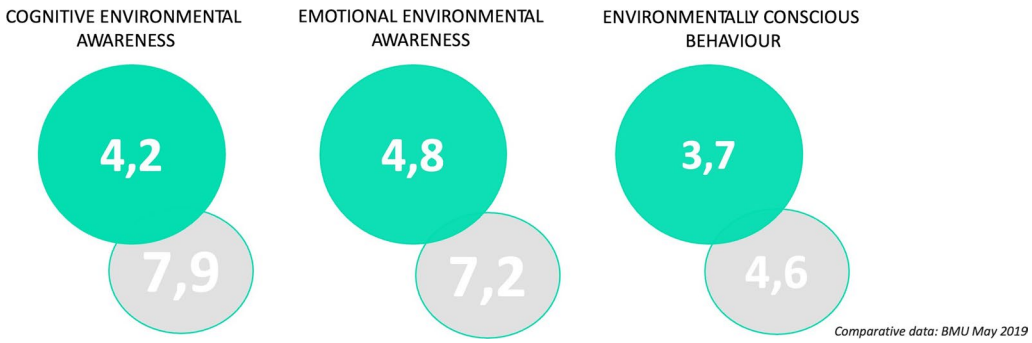


**Fig. 7** Level of cognitive environmental awareness, emotional environmental awareness, and environmentally conscious behaviour among the German population in comparison with data from 2019

on potential active support: only 44% of those without knowledge indicate a willingness to become actively involved, in contrast to 69% of those with knowledge of green hydrogen.

The overall high level of approval despite limited familiarity with green hydrogen reflect the findings of Achtenberg et al. [66] on the role of knowledge—in that it only leads to increased acceptance under certain circumstances and in conjunction with factors, such as trust and cultural predispositions. The substantial level of local approval shows that local acceptance is better explained in terms of place attachment than as a matter of NIMBY reactions [27, 28, 67]. Overall, the combination of limited knowledge and fundamental openness towards hydrogen technologies revealed by the survey is consistent with earlier findings from Germany [36, 39], the Netherlands [42, 66], the United Kingdom [68, 69] and Spain [70]. Our findings on the influence of age and level of education on hydrogen acceptance likewise confirm the results of earlier studies [66, 71, 72]. A clear difference can, however, be observed between public familiarity with hydrogen in general, and green hydrogen in particular. Whereas many people have a rough understanding of the former, having learnt about hydrogen in school or having encountered it in a range of practical settings,[1] the term "green hydrogen" has not yet entered the broader public lexicon. Nevertheless, the population is very open to and willing to use green hydrogen, in large measure thanks to its expected positive impact on environmental protection and the achievement of climate targets [21, 36]. The issue of safety, on the other hand—to which technology experts often attach great importance—turns out not to be a particularly decisive factor for green hydrogen acceptance [68, 69].

[1] This is suggested by our qualitative findings from the interviews and participatory workshops.

### *Environmental awareness in Germany and its impact on green hydrogen acceptance*

With a descriptive and statistical analysis, we analyzed the following hypotheses. While the first was informed by observation of public debate and societal changes as a result of the COVID-19 pandemic compared to the findings based on the qualitative data, we derived the second based on the studies by Scholl et al. [73] and BMU [61] and transferred it to the context of green hydrogen.

**Hypothesis 1.1.** The COVID-19 pandemic has put environmental awareness and behavior into the background.

**Hypothesis 1.2.** Higher levels of cognitive environmental awareness and cognition have a positive impact on approval of green hydrogen.

As part of the survey we assessed the environmental awareness in Germany, as conceptualised by Scholl et al. [73]. Compared to the most recent biennial representative survey of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) [61] our findings reveal a marked decrease in cognitive environmental awareness (from 7.9 to 4.2), emotional environmental awareness (from 7.2 to 4.8) and environmentally conscious behaviour (from 4.6 to 3.7) (Fig. 7).

The comparison with the data of the BMU has to be made with restrictions, since it is not a longitudinal study and different persons were interviewed in both studies. Nevertheless, it is possible to make careful descriptive assumptions about the background of the partially strong discrepancies. The significant decrease in environmental awareness can be explained by the drastic shift in public attention that occurred between the two surveys as a result of the COVID-19 pandemic. Whereas environmental and climate protection continually stood at the centre of public discourse in 2018 and ultimately led to the start of the Fridays for Future movement, our survey coincided with the outbreak of COVID-19 in Germany, the effects of which had a particularly strong grip on

**Table 1** Results of the linear regression

| | Non-standardized coefficients | | Standardized coefficients | *T* | Sig. |
|---|---|---|---|---|---|
| | Regression coefficient | Standard error | Beta | | |
| (Constant) | 0.882 | 0.078 | | 11.242 | 0.000 |
| Environmental affect | 0.076 | 0.018 | 0.115 | 4.204 | 0.000 |
| Environmental cognition | 0.133 | 0.019 | 0.192 | 7.023 | 0.000 |
| Dependent variable: local acceptance of green hydrogen | | | | | |

the public's attention in May 2020. Accordingly, issues related to environmental and climate protection are seen to have lost much of their cognitive and emotional significance. The somewhat less pronounced decline in environmentally conscious behaviour can be accounted for by the fact that patterns of behaviour are slower to change and less easily influenced than cognition and affect. These findings demonstrate that environmental awareness is not yet embedded deeply enough in German society to withstand dramatic shifts in public attention. Moreover, our findings reveal the scope of the challenge involved in restoring—and expanding on—pre-pandemic levels of environmental awareness, and bringing-related issues, targets and tasks back to the forefront.

Using a linear regression analysis, we were able to determine the influence of cognitive and emotional environmental awareness on the approval of green hydrogen. Table 1 shows the results of the linear regression. The regression model with the dependent variable local acceptance of green hydrogen[2] and the independent variables environmental cognition and environmental affect (for a description of the independent variables see Sect. "Description of questionnaire and variables") was significant ($F(2, 2051) = 86.67$, $p < 0.001$). The results indicate that a cognitive environmental awareness level increased by one unit is related to probability for local approval increased by 0.076 scale points and an emotional environmental awareness increased by one unit is related to a probability of local approval increased by 0.133 scale points.

The correlation observed in both instances underlines the importance of environmental awareness in promoting green hydrogen acceptance [35, 74]. Whereas the former requires focussing on information and convincing factual arguments, the latter calls for measures that operate on an emotional level. In light of the current urgent need to activate advocates of green hydrogen [34, 75], our findings thus provide a blueprint for the design of measures that effectively promote acceptance. Merely relying on arguments based on technological advantages or logical necessity will not suffice; rather, green hydrogen and its specific practical applications need to be embedded in visions that are as captivating as they are robust.

#### *Participation, trust and green hydrogen acceptance, part I*

Our quantitative survey also served to test six hypotheses on the significance of trust and participation to green hydrogen acceptance.

Building on earlier findings on the role of trust in various actors [33, 55, 76–78] and in institutions that ensure the just distribution of costs and benefits [33, 79–82], our first two hypotheses operationalise the relationship between trust and acceptance:

**Hypothesis 1.1** A positive correlation exists between green hydrogen acceptance and the perceived trustworthiness of government, business, science and the media.

**Hypothesis 1.2** A positive correlation exists between green hydrogen acceptance and high levels of confidence in the fair distribution of the costs and benefits of green hydrogen use.

Regarding hypothesis 1.1, our findings reveal a significant correlation between local green hydrogen acceptance and the perceived trustworthiness of the scientific sector ($rs = 0.319$, $p < 0.001$, $n = 2088$[3]), corresponding to a moderate effect following Cohen [62]. Local green hydrogen acceptance is likewise seen to correlate significantly with the perceived trustworthiness of government actors ($rs = 0.209$, $p < 0.001$, $n = 2088$) and the media ($rs = 0.212$, $p < 0.001$, $n = 2088$), in both instances corresponding to a small effect following Cohen [62]. The

[2] The question was (originally in German): "How do you feel about the use of green hydrogen in your city/community?". Four-point Likert scale "very positive"—"very negative".

[3] Summarised values for the perceived trustworthiness of government, the media, science and business are as follows: science: 52% very/somewhat trustworthy—37% both in equal measure—11% very/completely untrustworthy; government: 31% very/somewhat trustworthy—44% both in equal measure—25% very/completely untrustworthy; media: 25% very/somewhat trustworthy—31% both in equal measure—33% very/completely untrustworthy; business: 22% very/somewhat trustworthy—44% both in equal measure—34% very/completely untrustworthy.

perceived trustworthiness of the business sector, on the other hand, does not correlate significantly with local green hydrogen acceptance. With respect to hypothesis 1.2, our findings show local green hydrogen acceptance to correlate significantly with confidence in the fair distribution of the costs and benefits of green hydrogen use ($rs = 0.258$, $p < 0.001$, $n = 2088$), corresponding to a small effect following Cohen [62]. These findings reveal trust and perceived distributive justice to be relevant acceptance factors for green hydrogen, with trust in the scientific sector emerging as particularly influential.

The next two hypotheses deal with the effect of participation on green hydrogen acceptance, building on earlier findings that reveal participation to have a positive impact on the acceptance of other renewable energy technologies [83–89]:

**Hypothesis 2.1** People with participatory experience display higher levels of approval of green hydrogen.

**Hypothesis 2.2** People who assess their own participatory experiences favourably display greater willingness to actively support green hydrogen adoption.

With respect to hypothesis 2.1, our statistical analysis reveals significantly higher levels of approval of green hydrogen among people with participatory experience (mean 1.69, mean rank 874.73), compared to those without (mean 1.94, mean rank 1089.70).[4] The asymptotic Wilcoxon test yields a $z$ value of $-7.494$, a $p$ value of $< 0.001$, and an $n$ value of 2088. The $r$ value of 0.164 corresponds to a small effect following Cohen [62]. Regarding hypothesis 2.2, people who assess their participatory experiences favourably display significantly greater willingness for active involvement (mean 1.88, mean rank 147.49) than those who do not (mean 2.31, mean rank 192.18).[5] The results of the asymptotic Wilcoxon test are $z = 3.445$, $p < 0.001$ and $n = 365$. Here, the $r$ value is 0.180, corresponding to a small effect following Cohen [62]. These findings indicate a notable correlation between participation and approval of green hydrogen, and between the quality of people's participatory experiences and their willingness to become actively involved in promoting its use.

The final two hypotheses focus on the relationship between participation and trust:

**Hypothesis 3.1** Positive participatory experiences correlate positively with trust in government, business, science and the media.

**Hypothesis 3.2** Positive participatory experiences correlate positively with expectations that the costs and benefits of green hydrogen use will be distributed fairly.

Regarding hypothesis 3.1, our findings reveal a highly significant correlation between positive participatory experiences and trust in various actors. This is particularly true of trust in government ($rs = 0.762$, $p < 0.001$, $n = 426$), science ($rs = 0.556$, $p < 0.001$, $n = 426$) and the media ($rs = 0.741$, $p < 0.001$, $n = 426$), with the correlation in each case corresponding to a large effect following Cohen [62]. In the case of trust in business ($rs = 0.402$, $p < 0.001$, $n = 426$), the effect is moderate, per Cohen's scale [62]. Our analysis likewise confirms hypothesis 3.2, showing the correlation between positive participatory experiences and expectations of fairness to be highly significant ($rs = 0.418$, $p < 0.001$, $n = 426$). The effect in this instance is moderate, following Cohen [62]. These findings indicate a strong to moderately strong positive correlation between positively assessed participatory experiences and trust in various actors and institutions.

## Qualitative data

### Case selection

In addition to the representative survey discussed above, the findings presented in this paper are based on a regional case study on green hydrogen acceptance carried out in and around Leipzig, with a specific focus on the town of Grimma and its surroundings. This area was selected for two reasons. First, the study called for a region, where initial forays into green hydrogen use have already been undertaken. Central Germany's long-standing tradition as chemical industry hub, its well-developed hydrogen infrastructure, and the local presence of research organisations and companies that have been dealing with green hydrogen for some time, therefore, made this region an ideal candidate, with local industrial initiatives to introduce or expand green hydrogen use in and around Grimma'[67] providing an additional argument for focussing on this area in particular. Second, the research project that forms the basis of this paper was conducted in cooperation with a network of local organisations working towards turning the area into a hydrogen model region[8]—which made selecting interviewees and workshop participants significantly easier. At this point it has to be mentioned that the distribution of the participants in the quantitative and qualitative part differs with regard to their geographical location (whole Germany vs.

[4] On a scale of 1 to 4, where 1 = very positive, 2 = somewhat positive, 3 = somewhat negative and 4 = very negative.

[5] On a scale of 1 to 4, where 1 = very willing, 2 = somewhat willing, 3 = somewhat unwilling and 4 = very unwilling.

[6] Cf.: https://www.lvz.de/Region/Grimma/Grimma-soll-ein-Wasserstoff-Standort-werden.

[7] https://www.mdr.de/wissen/wasserstoffzug-leipzig-grimma-100.html.

[8] https://www.hypos-eastgermany.de/en/.

specific location). Even though the general public debate about green hydrogen in Germany has gained significant momentum, since the data were collected and published, we do not expect that this has significantly altered its acceptance. Thus, while the general awareness may have increased and the relevance of its role in the context of the energy transition may also be assessed more highly, the arguments for or against the greater (local) use of hydrogen do not seem to differ significantly.

## Methodology

Qualitative methods aid in understanding and explaining complex social interactions and relationships [26, 90, 91]. Insofar as qualitative research is primarily geared towards in-depth understanding [92], the findings from our regional case study are not themselves directly generalisable, yet allow for certain generalised conclusions when viewed in combination with the quantitative findings from the representative survey [93]. In particular, our qualitative findings facilitate a clearer understanding of the respective roles of trust and participation.

First of all, a total of 24 semi-structured interviews were conducted with members of the general public ($n=12$) and representatives of government ($n=4$), science ($n=2$) and business ($n=6$), so as to cover the broadest possible range of perspectives [94]. Potential interviewees were identified and contacted directly [95] or—in the case of the local general population—additionally recruited by means of a call for participation distributed via local newspapers, social media, posters, and on- and offline networks. The interviews took place between July and September 2019 and in all but two cases were conducted in person. Each interview lasted 60 min and made use of one of two distinct interview guides, respectively, designed for respondents from civil society and interviewees from the other three fields. All interviews were voluntary and were recorded with consent [96]. The recordings were subsequently transcribed [97] and analysed on the basis of a deductively developed and inductively supplemented codebook consisting of 6 main categories and 33 subcategories [98], using Mayring's qualitative content analysis [99, 100] and with the help of MAXQDA software.

Second, two workshops lasting 6 h each were conducted in December 2019 in Grimma and in February 2020 in Leipzig, with two separate participatory workshops totalling 51 participants. Variously representing civil society, local government, business and science, and possessing greatly varying prior knowledge of green hydrogen, the members of each participatory workshops were given the opportunity to engage in equitable dialogue through a process of participatory design [101–103]. Participants were recruited by means of open calls for participation distributed via local networks, on- and offline media, social media, flyers and posters. Although we aimed to achieve as much balance as possible, both groups contained a majority of older participants (aged ~ 45 and above) and men. The overall aim was to gain a better understanding of different perspectives by means of a suitable workshop-based approach, while facilitating mutual dialogue and the consolidation of a diverse range of views into a shared, socially accepted vision for local green hydrogen use.

## Results

### *General findings*

Overall, in spite of the public's self-ascribed limited knowledge of green hydrogen, we were able to observe a high level of general and local approval in the investigated region. Two factors emerged as particularly decisive for acceptance of green hydrogen, namely, its perceived environmental and climate friendliness, and its capacity to help address specific local needs (e.g., within the field of mobility) and current challenges (e.g., with respect to structural change and job creation) by utilising the region's distinct capabilities (as long-standing chemical industry hub). In general, the greatly varying levels of trust placed in representatives of government, the media, science and business, and in the institutions and processes accompanying the introduction of new technologies, could be seen to play a major role.[9]

### *Participation, trust, and green hydrogen acceptance, part II*

In the absence of prior knowledge on which to base their assessment of green hydrogen, participants in the interviews and participatory workshops were seen to fall back on perceptions of various aspects of their local context. This consisted, first, in the activation and transference of more or less explicitly comparable experiences—for instance, with infrastructure projects—to the introduction of green hydrogen. This was particularly evident in participants' reported perception of government and industry processes, and the extent to which they trust the various responsible parties. Here, a complex picture emerges. Whereas positive personal experiences have led to a large degree of trust in municipal-level government actors, the same is decidedly less true for all higher level government institutions and decision-making processes, which tend to be seen as slow, of questionable integrity and dubiously motivated. Companies are generally

[9] On the basis of the qualitative findings we derived twelve acceptance factors for green hydrogen, which were then operationalised in a practical guide to the implementation of green hydrogen projects. The guide (in German) can be downloaded here: https://www.cerri.iao.fraunhofer.de/de/projekte/AktuelleProjekte/hypos.html.

viewed with scepticism and considered untrustworthy, with the exception of (very) small local businesses. By contrast, the scientific sector enjoys a large degree of trust, almost without exception.

Second, regional self-image could be seen to have a substantial impact on acceptance. Participants were seen to deliberately integrate green hydrogen into their understanding of their region as a traditional chemical industry hub affected by structural change and fighting for a sustainable future. Drawing various distinct connections between the technology and their own region helped participants come to two favourable conclusions regarding local green hydrogen use. First, a very large majority deemed their region well-equipped to use green hydrogen, thanks to its existing infrastructure, prior history, and knowledgeable individuals and organisations. Second, as a sustainable energy technology, green hydrogen was identified as a means of solving important local challenges, with respect to the transition to green energy, job creation and mobility. Thus, in addition to subjective factors, local context, as well as the varying extents to which past experiences have led people to trust different actors, institutions and processes, could be seen to have a major impact on green hydrogen acceptance in the investigated region.

Furthermore, most participants in the case study were seen to consider participation an important and effective tool for promoting social acceptance. Particularly in the run-up to specific planning or implementation projects, it is seen as a means of informing the public and other stakeholders, and of facilitating direct communication between different actors. Participation is thus considered a valuable means of xxx disalienating existing structures and breaking down occasionally hardened fronts between government, business, science and the media on one hand, and civil society on the other. The inclusion of representatives of the scientific sector is seen as particularly important, given their role as neutral and knowledgeable parties to be consulted in case of uncertainty. Moreover, engaging in direct dialogue with government and civil society is seen as a way for research organisations and businesses to fulfil their respective social responsibilities.

Certain differences between the two participatory workshops showed participation to be especially conducive to green hydrogen acceptance when people share a common motivation and willingness to become involved (a "reason why"). This not only points to the significance of group composition and dynamics to participatory processes [39], but also highlights two key factors for the successful promotion of acceptance. First, the methods employed in guiding participatory processes, and the quality of the resulting process itself, are fundamental to overcoming multiple hierarchies and asymmetries (e.g., those resulting from different levels of knowledge) so as to facilitate equitable dialogue. Second, inasmuch as acceptance depends on sustained and personally meaningful involvement, it is important to approach participation from a long-term perspective. In addition, transparency and honesty regarding the potential outcome and limits of any given participatory process are key to avoiding disappointment, which may otherwise adversely impact acceptance.

Taking the issue of trust into account, the participatory workshops were methodologically designed to enable participants to find a common language for addressing complex questions related to local green hydrogen use. Through a carefully guided process employing methods from the field of participatory design, a space was created for participants to get to know a variety of perspectives and arguments, build mutual understanding, and develop a shared vision. In addition, having a neutral research organisation in charge of recruitment and moderation helped make the involved parties more open to the process and to cooperation with one another. Their joint development of a shared vision for regional green hydrogen use could thus foster mutual trust while enabling especially members of the public to understand and contribute to an otherwise opaque and impenetrable decision-making process.

Participants in both workshops expressed the need for continued dialogue over a longer period of time. This shows that whereas short-term participation can create mutual understanding, trust can only be sustainably established via iterative or longer term participatory processes. Here, however, a certain paradox arises: while participation can ultimately strengthen trust, the willingness to get involved in participatory processes and engage with other perspectives presupposes a certain measure of trust. Accordingly, despite our inclusive approach and efforts to keep the barrier to entry as low as possible, people who expressed little to no trust in the first place proved difficult to recruit for our study.

Overall, our findings show that given the development and proper implementation of appropriate methods, participation has the capacity to lay the groundwork for trust, which is then to be further cemented over the medium and long term.

## Discussion

### Trust is crucial for green hydrogen acceptance

Our findings reveal trust in actors and institutions responsible for ensuring the fair distribution of costs and benefits to be a significant acceptance factor for green hydrogen. In particular, a relatively strong positive correlation can be observed between acceptance and trust in science. This can be explained by people's tendency

to think of green hydrogen primarily as a product of scientific research, when tasked with evaluating it in the absence of a particular practical application and corresponding context. The absence of a specific use case in our study likewise explains why acceptance could be seen to correlate weaker with trust placed in media outlets to provide impartial information, and with trust in government actors. Given the latter's decisive role in the implementation of new technologies, we expect trust in government to become a far more significant factor in specific use cases. Similarly, the insignificant correlation between local acceptance and trust in the business sector can be explained by the fact that the public does not associate (green) hydrogen with particular companies—and unlike Emmerich et al. [74], we did not make use of any hypothetical scenarios capable of triggering such associations. The weak correlation between expected distributive justice and acceptance can be explained by the public's lack of experience to date with the costs and benefits of green hydrogen use. Our data nonetheless indicates the existence of a fundamental correlation, which we expect to gather in significance as public experience increases.

As our qualitative findings confirm, only the scientific sector enjoys a large measure of trust. By contrast, little trust is placed in the media, and people tend to be sceptical or very critical of government and business. Our qualitative findings, furthermore, reveal trust in government and business actors to be a relevant insofar as they are held responsible for properly weighing costs and benefits in terms of sustainability and the common good, and deciding on an implementation strategy befitting the self-image of the region in question. This is in line with Devine-Wright's [27, 30] thesis on the significance of place attachment and place identities to acceptance, and highlights the importance of attaining a symbolic fit between place and technology. The latter was particularly noticeable in our case study, where participants could be seen not only to think in terms of positive user experiences and cost savings, but also to explicitly and productively embed green hydrogen in their vision and understanding of community, belonging and regional identity.

We are thus able to qualitatively expand upon our quantitative findings on the role of trust. What emerges as relevant is the extent to which actors and institutions are trusted to manage the introduction green hydrogen in harmony with the local prioritisation of regional self-image and social values, such as fairness [cf. 81], as opposed to merely acting in self-interest.

The results of our study build on earlier findings on the role of trust in acceptance in the context of geothermal energy [55, 78] and wind energy [81, 82, 104], and highlight the importance of trust in the relevant institutional framework [29, 80, 81, 105]. This encompasses more than just social trust [106] as a means of dealing with personal lack of knowledge [68, 76, 77]; rather, it is above all a matter of trust in the actors and processes that determine how green hydrogen is introduced and used. Our findings, furthermore, confirm the importance of trust and fairness at community level as described by Wüstenhagen et al. [24], as well as Mumford and Gray's [44] findings on the impact of low levels of trust in companies within the energy sector. In addition, our findings echo those of Pellizzone et al. [54, 55], which reveal a "deep-seated distrust in institutions, companies and decision-makers" among the general population while identifying questions of fairness and the common good as decisive for acceptance. Scherhaufer et al. [80] likewise emphasise the importance of fairness, placing it in connection with policy cores, which are unlikely to change and in turn guided by so-called deep core beliefs—an example of which would be a region's self-image, which can be described as a deep core belief about its values.

#### The quality of participatory processes is important for acceptance

Although our chosen research design does not allow for causal conclusions, a remarkable correlation can nonetheless be observed between green hydrogen acceptance and participation. Individuals with participatory experience display significantly higher levels of acceptance, from which we infer that in addition to openness, environmental consciousness and knowledge, a crucial role is played by people's perceived capacity to influence processes and decisions that affect their personal circumstances (e.g., the introduction of a new technology). Through participation, people experience self-efficacy and gain a better understanding of different attitudes and needs.

The correlation of favourably assessed participatory experiences with acceptance is particularly interesting. It shows, first, that it is not the mere fact of participating that is important, but rather the (perceived) quality of the participatory experience itself—measured not only in terms of methods and results, but also such aspects as the attitude of the organisers and whether participants feel respected. Second, positively assessed participatory experiences are specifically conducive to active support, which is vital to social acceptance of renewable energy technologies in Germany [34, 75] (cf. "Environmental awareness in Germany and its impact on green hydrogen acceptance").

The findings from the participatory workshops, furthermore, show that sound methodology and properly conducted processes are key to enabling successful

deliberation and exchange of different perspectives, the development of a common language and—if need be—the reconciliation of different interests. This highlights the necessity of developing and testing sound methodological approaches to optimise participatory processes, as pointed out by Scherhaufer et al. [80] in their discussion of the effectiveness of visualisation. Building on Lienhoop's [86] argument that different levels of participation are needed along with "substantial improvements so as to enhance procedural justice", our findings underline the importance of the quality of participatory processes, as measured not only in terms of their end results, but also in terms of procedural fairness, and transparency with respect to the potential outcome and impact of the process in question. Overall, our study corroborates earlier findings on the role of participation in acceptance with respect to other forms of renewable energy [34, 55, 104, 107, 108] and the significance of fairness in participation [81, 83, 109] while expanding on the importance of methodological soundness and the quality of participatory processes and experiences. Building on existing research on the negative impact of alibi participation on acceptance [84, 110, 111], it would at this point be possible to continue a micro-level investigation of particular participatory processes with reference to theoretical [e.g., 112] or practice-oriented [e.g., 113, 114] efforts to satisfy the demand for increased participation enshrined in official policy.

**Recurring positive participatory experiences promote trust**

The quantitatively calculated positive correlation between participation and trust is likewise confirmed by our qualitative findings. The strong correlation between favourably assessed participatory processes and professed trust in government, science and the media shows that inclusion in planning and decision-making processes enables people to gain an understanding of different perspectives, decisions and compromises, while a positive perception of said processes can help strengthen their trust in the relevant actors and institutions. Conversely, those professing higher levels of trust are more likely to form a favourable assessment of their participatory experiences.

The smaller effect observed in the case of trust in companies can be explained by their tendency to withdraw from the spotlight in predominantly government-steered participatory processes marked by conflict. Combined with the fact that people with high levels of trust in business are likewise less likely to take part in government-steered, public participation processes, this means that companies benefit less from the positive impact of trust.

The significant correlation between positively assessed participatory experiences and expectations that the costs and benefits of green hydrogen usage will be distributed fairly similarly shows that the methodological design of a given participatory process affects participants' perceptions and expectations of fairness. Conversely, people with high levels of trust in institutions responsible for upholding distributive justice are more likely to describe participatory processes as successful.

Our qualitative findings also provide further evidence of the paradox mentioned in Sect. "Participation, trust, and green hydrogen acceptance, part II" above. For the most part, the people we managed to recruit for our interviews and participatory workshops displayed at least some measure of basic social trust. Individuals whose trust had been largely or fundamentally eroded, however, were far less receptive to our recruitment strategies and proved difficult or impossible to include in the process.[10] Nevertheless, by providing the necessary framework and methods for equitable dialogue and mutual understanding, the participatory process could be seen to have a positive impact on participants' trust. Although this shows that participation can promote trust, we maintain that a certain measure or minimum level of trust should not become a prerequisite for inclusion in participatory processes, lest they become incapable of reaching those members of the public who are more given to distrust. This would in turn not only serve to widen the social gap between the more sceptical and more trusting segments of society, but may also make widespread social acceptance impossible to achieve.

The bilateral, interwoven relationship between trust and positive participatory experiences makes their mutual reinforcement possible, especially over a longer period of time. Accordingly, as recurrent positive experiences can capitalise on and strengthen existing trust, the design of participatory processes needs to adopt a long-term perspective. This is confirmed by the desire expressed in our study—by both interviewees and participatory workshops participants—for continued dialogue and for joint deliberation to take place on a more permanent basis. Participation should thus become systemic and be organised on a recurring or long-term basis, so as to effectively build trust and avoid the risk of simply preaching to the choir.

Against this background, we argue that social acceptance should be understood as a matter of responsible innovation [45], in acknowledgement of the need to open the innovation system to civil society. This can be achieved by means of long-term public participation. By

[10] For instance, out of nearly 50 people who were directly contacted via e-mail and/or telephone, only 12 ended up taking part in the process. The remaining participants were recruited via an open call for participation distributed via posters, flyers and mailing lists.

building trust over the long term and promoting acceptance at an early stage, responsible innovation's central tenet of democratisation can be embedded in the development and use of green hydrogen technology.

First of all, we maintain that approaching acceptance as a matter of responsible innovation entails a stronger focus on systemic measures, so as to firmly cement the role of social values in steering green hydrogen use by means of cross-sectoral participation—and in particular through the involvement of civil society. This means taking the general public's knowledge seriously and affording the public as actor more trust, responsibility and authority—which in turn calls for research into diverse forms of interaction and dialogue.

Second, there needs to be a stronger focus on innovation processes. Efforts and strategies to create conditions amenable to acceptance should look not only towards the subject, but also the object of acceptance and its surrounding context. It does not suffice to try to determine which individual factors—for instance, psychological characteristics—tend to favour acceptance. Instead, we argue that technology acceptance also requires investigating and (re-)shaping research, development, planning and implementation processes, with the resulting participatory innovation processes providing a space for different forms of practical involvement and the expression of a variety of reactions. Acceptance is thus not treated as a given outcome; instead, as particular practical solutions based on green hydrogen technology are collaboratively developed and implemented in response to specific needs, the relevant acceptance criteria are at the same time collaboratively inscribed in the solutions themselves.

Adopting a participation-oriented understanding of acceptance as a matter of responsible innovation could serve to address numerous limitations of acceptance research—which has been criticised for not affording the public enough trust [104], not paying enough attention to different forms of (expressing) approval or rejection [31, 115], using predominantly quantitative approaches that potentially rely on a simplistic understanding of acceptance, thus overlooking important aspects thereof [31, 68], displaying a pro-acceptance bias in treating acceptance as both given and normatively desirable [116], and generally inadequately factoring in the relevant institutional and sociopolitical context [29, 80, 105]. By abandoning a top-down perspective [115] in favour of a participatory governance framework predicated on the systemic integration of civil society, more trust is placed in societal actors and in their knowledge, the focus is shifted to the institutional context surrounding innovation, and a greater variety of reactions is made possible via early participation—all of which serves to broaden the formerly narrow concept of social acceptance. Thus, our findings reveal the limits of a passive understanding of acceptance that treats the acceptance object as given [26] while highlighting the sociopolitical dimension of innovation and acceptance [60].

## Conclusions

### General implications

To investigate green hydrogen acceptance in Germany, we chose a mixed-method approach, combining quantitative data from a representative survey with qualitative data derived from interviews and participatory workshops. Given its key role in sector coupling and the establishment of a sustainable energy system, green hydrogen is central to the process of social transformation accompanying Germany's energy transition. Since practical implementation of this technology is still at an early stage, early social acceptance can be promoted via responsible innovation and rollout processes, thereby avoiding the kinds of conflicts and delays seen in the case of other renewable energy technologies.

Overall, our findings show the public to be simultaneously very unfamiliar with (Fig. 2b) and very open towards (Fig. 6)—and in some cases even extremely interested in—green hydrogen, primarily thanks to the associations and promise of sustainability it carries. Trust is seen to be essential for acceptance: not only trust in science, government and the media (results hypothesis 1; Sect. "Participation, trust and green hydrogen acceptance, part I"), but also in institutions responsible for upholding regional values and ensuring the fair distribution of costs and benefits (qualitative data; Sect. "Participation, trust, and green hydrogen acceptance, part II"). What emerges as decisive in this regard is the extent to which the public is confident that green hydrogen will be used in accordance with the regional identity, that is regional values, demands and capabilities.

Second, our findings show participation to be an effective instrument for promoting acceptance in general and active support in particular, and that positive participatory experiences can play an important role in fostering trust (results hypothesis 2.2; Sect. "Participation, trust and green hydrogen acceptance, part I"). Creating such experiences requires the careful, scientific development and implementation of suitable participation formats and methods, which take the relevant sociopolitical context and participants' previous experiences into account, and which facilitate open and long-term dialogue (qualitative data; Sect. "Participation, trust, and green hydrogen acceptance, part II"). Simply ensuring that participation takes place is not enough: when the goal is to build trust and promote acceptance, non-positive or negative participatory experiences can exact a very high price [84, 110].

Accordingly, we conclude that instead of being treated as a mere tool or short-term measure, participation should be embedded within relevant institutions, structures and processes with a long-term view to building and strengthening trust.

Against this background, we argue that social acceptance of green hydrogen should be approached from the perspective of responsible innovation, and participation understood as a means of democratising innovation by systemically altering the relationship between civil society, on one hand, and government, science and business, on the other. This might be facilitated by the collaborative governance of the introduction and use of green hydrogen in a regional context. In this way, trust can be strengthened on a structural level, thus staving off potential conflicts in the medium and long term.

### Policy implications

Our study has revealed instances of significantly eroded public trust. In addition, the window of opportunity for cementing public positivity and openness towards green hydrogen is closing with increased use of the technology. Furthermore, any conflicts that happen to draw the public's attention risk creating a public image that can be difficult to change after the fact. All of these factors contribute to a certain level of urgency.[11]

Our findings carry certain implications both for innovation policy in general, and with respect to green hydrogen in Germany. In terms of the latter, we offer two sets of practical recommendations. First, there is a need for measures that increase public awareness and ensure widespread basic knowledge of green hydrogen [117]. It is important that the information be presented in an accessible format, so as not to exclude especially older segments of the population and those with lower or no academic qualifications. Special attention should be paid to transparency and a balanced presentation of the technology's advantages and disadvantages, current state of development and future possibilities, so as to avoid creating false expectations regarding sustainability. Second, advocates of green hydrogen need to be activated by means of participatory measures that target the emotional dimension of environmental awareness, for instance, via emotionally engaging visions for regional hydrogen use. This requires creating positive participatory experiences, and evaluating their impact in a scientifically rigorous manner.

[11] The federal government seems to have at least recognised the urgency and critical importance of social acceptance. The most recent amendment to the Renewable Energy Sources Act, which plays a central role in Germany's energy transition, lists "acceptance of the further expansion of renewable energies" as one of the six most important current issues.

Our findings, furthermore, support three broad recommendations for innovation policy. First, there is a need for substantial investment in systemic trust in government, science, the media, and institutions that safeguard distributive justice, so as to create a stronger basis for acceptance of new technologies and the transition to green energy as a whole—all of which is to be understood as falling under the remit of innovation and technology policy. Second, we recommend more clearly acknowledging the sociopolitical nature of innovation by understanding questions of trust and fairness as integral parts of innovation policy, which should systematically inform the shape of innovation processes—for instance, via the establishment of particular funding criteria or standardisation processes. Finally, it is necessary to keep exploring and testing ways of further structurally democratising the innovation system via participation—not only within academic research, but also, for instance, as part of municipal innovation projects.

### Limitations and avenues for further research

Despite combining a representative survey with qualitative data, our study faced certain limitations. First of all, as our investigation of social acceptance of green hydrogen took place at a very early stage of its deployment, we did not have the option of examining any existing implementation projects—and could thus only focus on the technology's potential use in participants' local surroundings. Second, our particular focus on a region with a long history in the chemical industry resulted in qualitative findings that are only generalisable in combination with the quantitative results of our representative survey. Nonetheless, as the combination of quantitative and qualitative methods proved useful in exploring the complexities of social acceptance, we encourage further studies using a similar mixed-method approach (Additional file 1).

Our findings indicate, first, that the relationship between institutional trust and regional values merits further investigation. This could aid in translating broad regional energy concepts into specific strategies or business models [118]. Second, suitable criteria for assessing participatory processes in terms of their impact on acceptance need to be developed and appropriately evaluated. Third, it is worth investigating the impact of various forms of recurring and long-term participation on institutional trust over a longer period of time. Fourth, further research needs to specify participation in terms of its timing in research, development and innovation projects, the responsibilities attributed to different stakeholders, and the knowledge required to initiate such processes. Finally, our attempt to conceptually and empirically interlink acceptance research and responsible

innovation gives rise to the following important questions. How can responsible innovation benefit from the scientific and methodological expertise of acceptance research? Which forms of systemic participation are particularly conducive to acceptance? What roles and processes would exist in a more democratic innovation system geared towards trust and acceptance, and which systemic adjustments would the establishment of such a system require?

## Supplementary Information

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**Additional file 1.** Supplementary material 1.

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**Author contributions**
JJH developed the concept of the study, lead both the data collection and analysis of qualitative and quantitative data as well as the writing of the paper. TK contributed to the concept development of the study, the literature review and the qualitative data collection and analysis. MJM contributed to the concept development of the study and the quantitative data collection and analysis. SK contributed to the concept development and the final writing of the paper. MS contributed to the writing of the paper and the conclusions. All authors read and approved the final manuscript.

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**Availability of data and materials**
The data sets used and analysed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate**
Not applicable.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare that they have no competing interests.

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