

Energy Rebels? How Households' Preferences for Decentralized Hydrogen Systems Misalign with Energy System Requirements

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Abstract— Using findings from a survey of 350 participants, we answer the question to what extent the trends towards more digitalisation and environmental awareness could create a market for decentralized hydrogen applications. The results show that while energy experts are sceptical towards the benefit of decentralized hydrogen applications and its high costs, households show a great interest in the hydrogen technology. The majority of the sample states that they are definitely or likely willing to invest in a hydrogen application. Innovative households even state a willingness to pay more (Ø 24% more).

Keywords—hydrogen, decentralized energy supply, self-consumption, household survey

I. INTRODUCTION

The transition of the energy system includes the increasingly active market participation of formally passive consumers via the installation of photovoltaic (PV) systems for decentralized production and on-site consumption of electricity. The concept of self-production and consumption of electricity is quite controversially discussed. Some studies stress economic inefficiencies [1], while others point to potentially rising grid fees [2]. Despite the controversy around self-consumption, studies show that not merely economic factors play a role in households' decision to invest in decentralized energy supply [3]. In particular, the possibility to contribute to the energy transition and to hedge against rising electricity prices are known to trigger a high willingness to invest – not only in PV systems but in additional energy storages to increase the potential benefit by storing excess electricity for a later use and thus increasing the self-consumed amount of electricity [4]. Studies show that currently more than 50% of PV systems are installed in combination with a

battery [5] even though there is rarely an economic case for the electrical storage [6]. Additionally, batteries are not able to store electricity for a long term, and are usually used to supply the households with self-produced electricity in the night time, when the sun is not shining. However, the highest electricity demand occurs in the winter month, while most of the solar electricity is produced in summer. To store the electricity produced in summer for a later use in winter, other storage technologies are needed.

With the development and thus expected cost reduction of hydrogen technologies, these technologies could be an option as seasonal storages in the near future. Some companies already announced the market launch of this technological solution, and promote self-sufficiency throughout the entire year [7]. The technology works as follows: an *electrolyser* uses excess electricity from the PV system to split water (H₂O) into its components hydrogen (H₂) and oxygen (O₂). The gaseous hydrogen can be stored e.g. in pressure tanks with very little storage loss over time. When electricity is needed, hydrogen and oxygen can be converted back to water in a fuel cell, generating electricity in the process. This concept has, however, one major drawback, which is its relatively low efficiency: current electrolyzers operate with an efficiency of around 70%, the pressurising of the hydrogen for the storage has an efficiency of 85-90%, and the fuel cell produces electricity with an efficiency of around 60% [8]. In sum, the roundtrip efficiency is only around 35%. The efficiency might increase with technical development, and if waste heat can be recovered for residential heating.

The currently low efficiency of these hydrogen storage systems and their high cost do not yet form an

economic case. However, as stated before, households invest in battery storages without a compelling economic case. Thus, the question arises whether households will also adopt hydrogen technologies as a seasonal storage for their self-produced electricity.

In this study, we therefore aim to answer the following research questions:

- *Is the German population willing to invest in hydrogen technologies? And, in particular, in hydrogen home storage systems?*
- *What are their motives?*
- *What is the potential market for hydrogen home storage systems?*

To answer these questions, a market research study was conducted, which is as described in the following.

II. METHODS

The market research survey was initiated within the project “EnDaSpace PLATON” funded by the Fraunhofer Society. The focus lies on estimating the potential market for decentralized hydrogen applications while considering certain restrictions and acceptance issues influencing the actual adoption of these technologies.

To be able to display a broad representation of interests within the population, and to focus on the most relevant subgroups, we derived our survey data from three selected groups: tenants, homeowners with a photovoltaic (PV) plant and homeowners without a PV plant. The data was obtained in December 2020 with the help of a market research institute, using an online survey that took about 30 minutes. Our final sample contains 350 complete datasets (female: n = 168, 48%). There was a good balance between younger and older participants (>50 years old: n = 221, 51%) with a rather high educational level (> A-level: n = 188, 54%). The dataset is structured as Tab. 1 shows:

Tab. 1: Sample structure of the quantitative survey

Group	tenants ^a	homeowners ^b without PV	homeowners ^b with PV
Nb. of participants	106	110	134
Share in survey	30%	31%	38%
Share in population ^c	58%	26%	6,6%

^a Tenants refers to tenants in apartments as well as houses.

^b Homeowners refers to owners of a single- or double-family house. Owners of apartments or multi-family homes are excluded from the analysis, since the sample was too small.

^c Shares taken from [9,10]

In order to assess a sufficiently high and comparable number of participants within each group, the distribution of groups is not representative regarding these characteristics. Thus, we weight our results regarding living situation and PV ownership according to the distribution in Germany given by the Federal

Statistical Office [9] and a survey on solar energy [10] to obtain results in line with the German population. Note that the numbers in Tab. 1 don't add up to 100%. Smaller groups, such as apartment owners, were excluded from the analysis, since their number in the sample was too low for an evaluation.

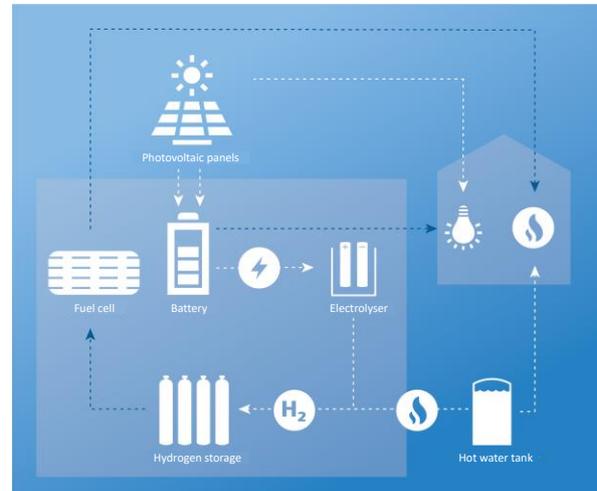


Fig. 1: Depiction of the decentralized hydrogen system shown to the survey participants

Questions of the survey addressed the interests and concerns towards hydrogen applications, their potential area of use, the approval of community use concepts and the general openness towards other innovative technologies, such as stationary battery storages. To allow for a common understanding of decentralized hydrogen applications, the survey participants were shown the depiction shown in Fig. 1 next to an explanatory text.

The survey also contained questions about the willingness to invest in decentralized hydrogen applications as well as a question on the willingness to pay more for such a technology. Assessing the willingness to invest aims at analyzing the potential share of “first-movers” or “innovators”, who are keener to adopt this innovative technology than the average population, and who are more willing to accept certain technical issues that can occur with new technologies.

III. RESULTS

A. Full sample

In the first part of this study, we examine the general knowledge about decentralized hydrogen in the German population and the attitude towards it (see Tab. 2). The participants were asked whether hydrogen will play a major role in the future or if it is a current hype that will lose its significance. The majority of the sample believes hydrogen to gain importance, only a

small minority thinks it will lose importance or is just a hype. However, 17% in the sample (or 19% in the German population) state they are unable to give an opinion or have not yet engaged with the topic.

Tab. 2: Answer to the question “How do you assess the future significance of hydrogen in the society?”

	Will gain + rather gain importance	Neither	Will lose + rather lose importance	Don't know
Sample	71%	11%	1%	17%
Weighted sample	66%	14%	1%	19%

In the next question, we asked about the knowledge of decentralized hydrogen systems. We find that less than half of the sample and the population has some understanding of the idea and only 4% state they have a pretty accurate idea of the concept (see Tab. 3). In sum, these two questions are crucial to later interpret the results better. We find that the topic of hydrogen and its technologies are rather new to a large part of the population.

Tab. 3: Answer to the question “Have you heard before about the possibility of using a hydrogen system (electrolysis + fuel cell) to store the electricity generated by a photovoltaic system in your own home?”

	Pretty accurate idea	Rough idea	No idea
Sample	6%	39%	55%
Weighted sample	4%	38%	57%

Between the different groups in the survey, i.e. tenants and homeowners, we did not find a significant difference in their knowledge about the technology or their opinion regarding the future significance of hydrogen in the society. Therefore, the difference between the sample results and the results of the sample weighted according to the three groups is rather small.

Subsequent to the question in Tab. 3, the participants were shown the explanatory figure and text (see Fig. 1). We thus assume that the participants have now some understanding of the technology.

The participants were then asked whether or not they would be ready to invest in a hydrogen system, like the one presented in the figure. The results (Tab. 4) show a rather positive attitude towards the technology.

Tab. 4: Answer to the question “Would you be ready to invest in the acquisition of a hydrogen system?”

	Yes + rather yes	Rather no + no	Don't know
Sample	54%	29%	17%
Weighted sample	43%	38%	19%

The participants were additionally asked which applications for the decentrally produced hydrogen would be interesting to them, and several options were given. The answers are as follows: *storage for self-produced electricity* (56%, weighted sample 50%), *heating* with hydrogen (47%, weighted sample 45%), *fuel station* for hydrogen cars (24%, weighted sample 21%), *feed-in* of hydrogen into the gas distribution system (17%, weighted sample 16%). 29% (weighted sample 40%) stated to have *no interest* in any of the options.

Further, the question was asked what the participants would fear most when adopting a hydrogen system. The most selected objection was that *cost* of the technology would be higher than potential savings (#1), followed by fear of *technical problems* (#2), and high *maintenance costs* (#3).

For the question in Tab. 4, we find a significant difference between the sample's groups: homeowners and in particular homeowners with a PV system are more likely to invest in a hydrogen system compared with homeowners without a PV system ($p \leq .001$) and tenants ($p \leq .001$). This is in line with our expectation, since homeowners are also the group for which the technology is most suitable since they own a house and have thus the option to install a PV system to produce electricity for the storage of which the hydrogen system is intended. In the following, we will therefore look more into the group of homeowners.

B. Homeowners

As stated above, homeowners with a PV system are most interested to invest in a hydrogen system (see Tab. 5).

Tab. 5: Answer to the question “Would you be ready to invest in the acquisition of a hydrogen system?” per group.

	Yes + rather yes	Rather no + no	Don't know
Tenants	38%	42%	21%
Homeowners	49%	36%	15%
Homeowner with PV	70%	14%	16%

	Yes + rather yes	Rather no + no	Don't know
Homeowner with PV + Battery	69%	17%	13%

Since we assume a connection between interest in a battery storage and a hydrogen storage, we evaluated the investment interest of PV and battery owners as well (N=52). However, there is no apparent difference between PV owners and PV + battery owners.

When asked about their motives, householders who would invest into a hydrogen system stated that they like to use an innovative product (mean=4.65), increase the value of their house (mean=4.47) and contribute to climate protection (mean=3.43). The respondents stated the same motives when asked for their interest in investing in a battery storage (innovative product (mean_{Batt}=4.00), increase the value of their house (mean_{Batt}=3.72), contribute to climate protection (mean_{Batt}=3.10)). We can thus assume that the markets for home battery systems and hydrogen systems overlap.

C. Innovators

13% of the sample (39 participants) not only stated their willingness to invest in a hydrogen system, but stated a willingness to pay more for a hydrogen system compared to conventional electricity and heating systems (on average 24% more). With the stated willingness to pay more, we assume this group to be the first movers in the adoption of decentralised hydrogen systems. In accordance to Roger's theory on diffusion of innovations [11], we refer to this group as "innovators".

To better describe this particular group, we use a Gaussian Naïve Bayes Classifier to identify the group's features. Naïve Bayes Classifiers are efficient models to handle any continuous data. The classifier learns parameters by looking at the statistical values of each feature for each class individually [12]. Using this method, we find that innovators generally *own a PV system*, they differ from non-innovators mainly in their greater *trust in energy supply organisations* (e.g. grid operators or local/national energy suppliers), their *lower fears associated with the use of hydrogen* (e.g. raw material use or efficiency) and their *higher affinity for technology* (e.g. use of an energy management system or automatic heating control). In addition, the group of innovators features *larger households*, *higher socio-political engagement*, and greater *concern with environmental issues*. Regarding socio-demographic characteristics, *higher education*, *younger age* and *higher household income* were important predictors of innovators. Based on these variables, it was possible to predict whether a person belongs to the innovators with an accuracy of 74.7%, 95%-CI [61.4%, 87.6%].

Tab. 6 gives a statistical description of the homeowners in our survey and the group of innovators in comparison with the homeowners in the German population.

Tab. 6: Descriptive statistics of innovators and homeowners from the survey in comparison with the German population of homeowners.

Mean values	Unit	Survey		Populatio n
		Inno- vator s	Home- owner s	Home- owners
PV owners	0/1 dummy	1	0.36	~0.2 ^d
Battery ownership	0/1 dummy	0.49	0.23	NA
Battery ownership or interest	0/1 dummy	1	0.59	NA
HH size	Number	3.2	2.7	2.4 ^e
Avg. age	Number	50	54	58 ^f
Children	0/1 dummy	0.59	0.33	0.21 ^e
Floor size	m ²	171	186	133 ^e
Electr. Consumption	kWh/yea r	3951	4476	3774 ^f

^d Survey of German homeowners on solar energy [10]

^e German Federal Statistical Office [13]

^f German Federal Statistical Office [13], the average age of the main income earner.

^g The average electricity demand of single family homes in Germany [14].

Based on these statistics, we estimate the innovators to be around 1 million households, i.e. 8% of the total population of owners of a single- or double family homes in Germany (around 14 million).

IV. DISCUSSION & CONCLUSION

A. Discussion

For the full sample, we find that the interest in the hydrogen technology is generally high, although there is an overall lack of knowledge as well as a share of around 40% with no interest in the technology. To answer the questionnaire for this study therefore required a relatively high level of imagination of the participants. We thus have to assume that their stated interests to invest in and their preferences for hydrogen might differ substantially from the actual investment when there is an established market for decentralized hydrogen systems.

Since the lack of knowledge was anticipated during the design of the questionnaire, we provided an explanatory figure and text for all participants. However, the presentation of the hydrogen system in the survey was only possible in an abbreviated form. This explanation will therefore not enable the participants without any beforehand knowledge to answer the questions with the same quality of response as their better informed peers. Additionally, to ensure a short and easy to understand presentation of the hydrogen system, we were required to omit some complex but relevant details, such as the system's low efficiency. One participant pointed out that she found this form of presentation leading. This has to be considered regarding the samples relatively positive attitude towards investing in a hydrogen system.

Despite the above described challenges, we found that the motives for investing in decentralized hydrogen systems are the same as for investing in stationary batteries. Also the target group is the same, i.e. homeowners with a PV system. In previous studies, a willingness to pay more for batteries was found, and a willingness to pay more for the hydrogen system was also stated by 13% of our sample. Thus, the possibility that an innovative share of homeowners will invest in hydrogen systems even though the technology does not form an economic case (yet), has to be considered.

B. Conclusion

The interest in hydrogen technologies is significant in Germany in particular within homeowners who already own a PV system for decentralized electricity production. Around 1 million households of the German population were identified as innovators, a group of first movers which stated a willingness to pay more for the technology than for conventional electrify supply systems. However, since the knowledge about the technology is still relatively limited, the actual willingness to pay can be different and is yet to be determined. Nevertheless, due to the similar motives for the adoption of hydrogen systems and home battery storages, there is the valid possibility that hydrogen systems could be adopted even if not efficient from an economical or a system perspective.

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