International Journal of
Environmental Sciences & Natural Resources
ISSN: 2572-1119

Juniper PUBLISHERS key to the Researchers

Research Article
Volume 34 Issue 4 - January 2025
DOI: 10.19080/IJESNR.2025.34.556397

Int J Environ Sci Nat Res

Acceptance of Hydrogen Among the Public in the Netherlands, a Longitudinal Study

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Submission: December 19, 2024; **Published:** January 24, 2025

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Abstract

In this manuscript we present the results of a four-year monitor among a representative panel of Dutch citizens on the knowledge, awareness and opinions regarding hydrogen. Hydrogen has the potential to play an important role in the energy transition and therefore receives a growing attention. At the start we wanted to know how the Dutch population felt upon hydrogen and its applications. By knowing how the Dutch feel about hydrogen, we could design campaigns to inform the public better and make these campaigns more tailored on the questions or worries the public has regarding hydrogen. In this contribution we present the results of these four studies.

Keywords: Hydrogen; Energy transition; Renewable energy sources; Greenhouse gas; Fossil fuels; Sustainable; Decarbonization; Environment; Water consumption

Introduction

Hydrogen is increasingly recognized as a pivotal element in the energy transition, which aims to shift from fossil fuels (that emit CO_2, a greenhouse gas) to CO_2-free, renewable energy sources. Hydrogen offers a sustainable solution due to its potential to store, move, and release clean energy, making it a versatile alternative to fossil fuels.

Hydrogen can be produced in elektrolysers, that split water into hydrogen and oxygen. If this is done using green energy, the resulting hydrogen is called *green hydrogen*. If nuclear energy is used, the resulting hydrogen is called *purple hydrogen*. Unfortunately, though, currently most of the hydrogen is produced fuels as natural gas and coal. If the CO_2 is released into the atmosphere, the hydrogen is called *grey hydrogen*. If the CO_2 is stored and captured, the hydrogen is called *blue hydrogen*[1].

Green hydrogen can be produced in times of a surplus of solar or wind energy, and used when there is a lack of sun and wind. Hydrogen can either be burned (to generate heat) or converted to electricity in a fuel cell. Hydrogen is also used a lot in industry, for instance in the production of steel and fertilizer. Now, the large majority of this industrial hydrogen is grey hydrogen. Replacing that by green hydrogen would entail a reduction of CO_2 emissions.

Looking at energy storage: compared to chemical batteries, hydrogen has upsides and downsides. The two main upsides are: 1) hydrogen can be stored long term – this in contrast to batteries, for the short term; 2) hydrogen has a higher energy density: one kilogram of hydrogen contains more energy than one kilogram of batteries. Storing energy in hydrogen has, however, also a downside: it is less energy effective than storing in a battery. Hydrogen can store more energy per kilogram than

[1]*There is political debate about what counts as green energy, and about storage of CO_2. Three issues are specifically thorny: 1. Should energy from biomass count as green energy? 2. Should nuclear energy count as green energy? 3. Is storing CO_2 underground acceptable? These debates are beyond the scope of this paper.*

batteries, but to do so, it requires a lot of energy. The reason is that hydrogen requires multiple steps: first conversion from electricity to hydrogen (using an electrolyser), then storage and/or transportation (requiring pumps, compressors, tanks, pipelines etc.), then conversion back to electricity (using e.g., fuel cells).

For this reason, Liebreich [1] advises to use hydrogen only for the long-term storage of energy; and as fuel for long distance trucks and boats - where batteries would be too heavy and impractical. For short term storage of green energy, the building environment, and for short distance transportation, batteries seem to be the better solution, but for long term (seasonal) and for large volumes, hydrogen is the 'missing link' in the energy transition.

Hydrogen's role in the energy transition is multifaceted and can be categorized in two main areas: (1) Energy Storage and Grid Management: Hydrogen can store excess energy generated from renewable sources like wind and solar, which are intermittent by nature. This capability is crucial for balancing supply and demand in the power grid and ensuring a steady energy supply despite fluctuating natural conditions [2]. (2) Decarbonization of various sectors: Hydrogen is being integrated into sectors that are hard to electrify, such as heavy industry and transportation (e.g., shipping and aviation), where it can significantly reduce carbon emissions [3]. Furthermore, to enable the further development of hydrogen, there is need for hydrogen infrastructures, such as fueling stations and pipelines, that are essential for the widespread adoption of hydrogen technologies. Specific for the Dutch situation, there is a so-called hydrogen backbone developed for the transport of hydrogen. These developments support the creation of a hydrogen economy, facilitating the shift from laboratory-scale research to commercial applications.

The transition to a hydrogen-based energy system is accompanied by the development of technologies for efficient hydrogen production, storage, distribution, and utilization. The integration of hydrogen into national and international energy policies is a critical step towards its role as a key component of a future sustainable energy landscape. This transition is supported by both technological advancements and growing governmental support through the formulation of hydrogen strategies and regulations aimed at fostering a sustainable, low-carbon economy.

However, the public acceptance of hydrogen energy varies widely, for instance on awareness and familiarity [4]. It showed that positive and negative affect, perceived benefits, preference for alternative technologies, trust, and age were significant correlates of acceptance of hydrogen applications. The public acceptance of hydrogen technology (vehicles and heating) is similar in different countries [5]. The general acceptance is supportive but general knowledge is low. Significant factors for acceptance are positive and negative affect, perceived benefits, preference for alternative technologies, trust, and age.

The public also shows a strong preference for hydrogen to be produced in environmentally (green or renewable hydrogen friendly ways [6,7]. Another issue is the trust in technology and the entities that promote it plays a critical role in public acceptance. Issues of safety, risk, and the benefits of hydrogen are central to building this trust. Effective communication and engagement strategies that highlight the concrete benefits of hydrogen for everyday life are essential for gaining public support [8].

But the public perceptions of hydrogen are dynamic and can change over time, influenced by factors such as media representation, governmental policies, and societal trends, and of course major incidents that might occur, like an explosion or other incident. Studies suggest that as people become more familiar with hydrogen technologies, their attitudes may become more positive, reflecting a growing acceptance of its role in energy transition [9].

Acceptance also varies by region and culture, indicating the importance of tailored approaches that consider local values, needs, and energy policies. This variability underscores the necessity for localized engagement strategies to enhance the public's understanding and acceptance of hydrogen technologies [10,11].

National and international research shows a clear picture: people are positive about hydrogen, but knowledge about hydrogen is limited. Unknown but not unloved. No association with insecurity [5,8,12-14]. More important than knowledge, however, are trust in technology, concern for the environment and taking care of the planet for the coming generation. Support for hydrogen technology has decreased in the Netherlands due to declining social confidence in science and technology in general [15]. Hydrogen offers opportunities for economic and regional development (such as employment and exports). However, the disadvantages for the environment must be minimized. Providing information had a positive effect on people who had no opinion about hydrogen but had no influence on the views of opponents [16]. Communication about hydrogen would be better off focusing on concrete benefits for everyday life, rather than on the possibility of storing electricity [8]. Even if consumers are positive about hydrogen, this does not necessarily mean that they will use hydrogen. This also depends on costs, technological maturity, availability and attractiveness of alternatives [5]. There are social barriers, favoring existing, known, traditional technologies over new, unknown, uncertain technologies. There are also economic and technical barriers. Economic barriers are much easier to break in highly developed and wealthy societies due to the amount of start-up capital available and higher levels of education [17].

Social acceptance of hydrogen becomes much less if hydrogen infrastructure (such as pipelines) is constructed in the own living environment [13]. The main factors influencing acceptance are prior knowledge, costs/risks, environmental knowledge, level of education and income, personal and distributive benefits, infrastructure availability and proximity to hydrogen facilities. For a successful hydrogen industry, the following elements are important: availability of infrastructure, affordability, involvement

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of the local community, contribution to regional knowledge development, conservation of biodiversity, safety and benefits for the local community [14].

The perceived advantages and disadvantages and the associated emotions are strong drivers for the acceptance of hydrogen technology. Most studies show that objective knowledge increases the acceptance of hydrogen. Being at least aware of hydrogen technology tends to increase hydrogen acceptance. Objective knowledge however has a relatively weak influence on hydrogen acceptance. Subjective knowledge appears to be more important in explaining acceptance than objective knowledge or awareness, but much of the influence of knowledge on acceptance is indirect, through the other factors. However, it is unclear which perceived benefits (e.g., energy security, environmental benefits), risks (e.g., destructive potential of a hydrogen leak), and costs (e.g., water consumption) most influence adoption.

Other commonly researched factors such as knowledge, experience, social trust, affect, personal norms and perceived fairness all help explain acceptance, but more research is needed to understand how all these factors work. Particularly because views and acceptance can change over time. The content of knowledge can also be relevant. Knowledge about the dangerous properties of hydrogen can increase the perceived risk, but knowledge about the different applications of hydrogen can increase the perceived benefits [1].

Hydrogen will not play a role in heating houses and in hydrogen cars according to some [16]. Hydrogen is especially necessary and unavoidable in industry, aviation and shipping.

Emission-free electric driving is possible with hydrogen cars or battery cars. The advantages of hydrogen cars are faster refueling, greater range, lower weight, insensitivity to cold weather and the use of less scarce materials. The major disadvantage of hydrogen driving is efficiency. If there is green electricity, it is better to use it immediately than to first convert it into hydrogen. There is three times as much green electricity for hydrogen cars needed than for battery cars to cover the same distance. In addition, there are currently only a few hydrogen filling stations, and hydrogen cars are expensive. It is much more effective and cheaper to drive battery electric cars than hydrogen cars [18].

There will only be opportunities for hydrogen cars in the longer term if cost calculations also include the costs of expanding the electricity grid. The total investment costs for the development of a hydrogen infrastructure may be much lower than for expanding the electricity network. Hydrogen cars are also becoming more cost-effective through innovation and economies of scale. Hydrogen cars and battery cars are seen as complementary rather than competitive. Battery cars are a good alternative to petrol cars and hydrogen seems to have opportunities in: vans, trucks, forklift trucks, garbage and sweeping trucks, shipping and public transport.

Hydrogen seems to have no role in heating homes due to its inefficiency, high costs and the availability of alternatives such as heat pumps and heat networks. Green hydrogen can best be used to replace gray hydrogen in industry. It produces a much greater CO_2 reduction there than when it is used in the residential environment. The EU's plan to blend hydrogen into the existing gas infrastructure is inefficient and leads to higher costs for users. Homes can be heated more efficiently with electric heat pumps and it is technically better and cheaper to only develop an industrial hydrogen network than to make the entire gas infrastructure suitable for hydrogen. Moreover, little green hydrogen will be produced in the EU in the coming years [19].

The year 2022 seems to be a turning point in the energy transition. Due to the war in Ukraine, countries around the world want to become less dependent on Russian energy and increase their own sustainable energy production. If sustainable investments are doubled by 2030 compared to current plans, it is even possible to achieve the Paris goals [20]. In rich Western countries the economy grew in 2023, but CO_2 emissions fell due to more sustainable energy, heat pumps, electric cars, lower industrial production, the switch from coal to natural gas and warmer weather. Globally, emissions reached a record high, but the pace is slowing. Since the Russian invasion of Ukraine, several Northwestern European countries have doubled their hydrogen production targets, and other countries are considering increasing their targets [21].

To test the acceptance of hydrogen in the Netherlands we issued a monitor with the help of a research agency, Newcom, that allowed us to ask panelists to complete a survey annually. The results of these monitors will be presented in this paper.

Methodology

The monitor was conducted through an online survey distributed among members of an ISO-26362-certified research panel organized by Newcom Research. The monitor involved Dutch individuals aged 18 and over. To ensure representativeness, the respondents were compared with the entire Dutch population (based on characteristics such as age, gender, and province of residence) and weighted where necessary to ensure that the outcomes provide a good representation of the Dutch population.

The survey has been carried out four times: a portion of respondents participated in one or more previous years. This has advantages and disadvantages. An advantage is that it then becomes easier to see differences in opinions from year to year because you can follow this for each respondent. A possible disadvantage, however, is that respondents learn from participating in the survey. This could skew the answers to the knowledge questions, one of the reasons that we included new knowledge items in every round. However, that effect does not seem to occur. 'Repeat participants' do not know more about hydrogen than 'First-time participants' (Table 1).

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Table 1: The total number of participants and the composition of the sample are displayed, according to the number of times respondents have participated.

Year	New	Previous Rounds			Total Response
2020	2012				2012
2021	1196	474			1670
2022	933	334	429		1696
2023	530	152	232	715	1629

We had at least 1629 respondents to each of the monitors, to test the levels of knowledge, awareness, and acceptance of hydrogen.

Results

The first question was how the respondents viewed climate change. The results are presented in Figure 1.

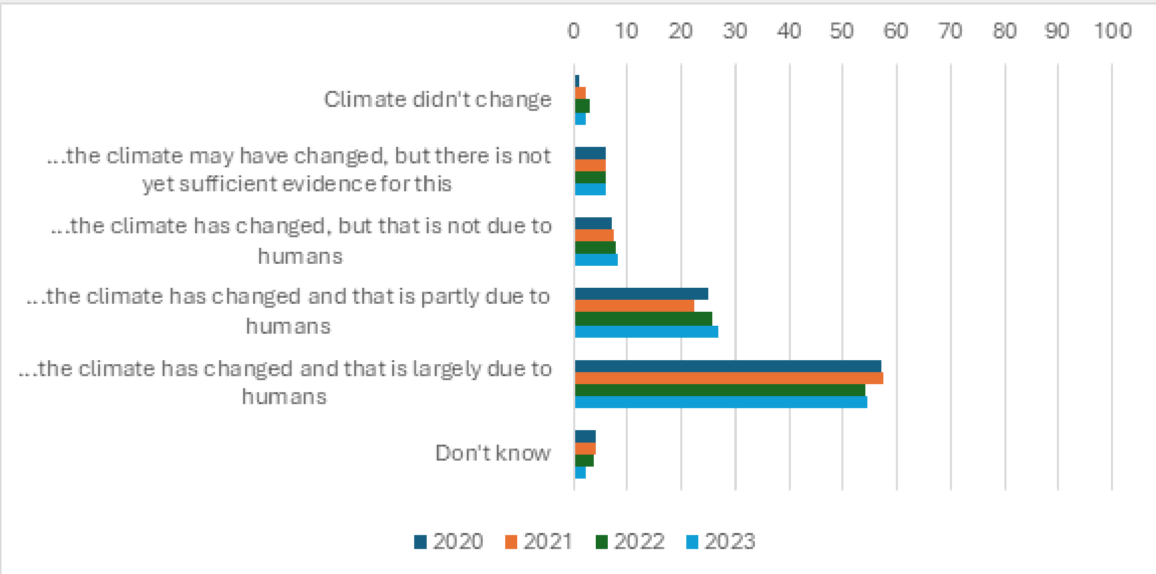

Figure 1: Are humans responsible for climate change?

As can be seen from Figure 1, most of the respondents agree that humans are (partly) responsible for climate change. Only minor differences can be seen from the different years. These figures are comparable to those of the Dutch Central Bureau of Statistics [21] that most of the people in the Netherlands are aware that climate change is occurring due to human activity.

During the four years of the study the invasion of Ukraine by Russia disrupted the energy transition in the Netherlands, partly because the Netherlands, just as many other European countries, is largely dependent on Russian natural gas. The Ukraine invasion plays an important role in the changing attitudes in the Netherlands, as can be seen in Figure 2.

In the three graphs we see clear the influence of the invasion by Russia in Ukraine on the attitudes of people in the Netherlands regarding energy saving, being independent from other countries for gas and oil and the switch to green energy. The war in Ukraine has led to more attention for energy independence, higher energy prices and more economical use of energy. In the energy trilemma (sustainability, security of supply and affordability), security of supply has become more important: Dutch people want to be less dependent on foreign (Russian) energy and want to develop more of their own energy sources. The increased energy prices since the war in Ukraine have also provided an incentive to insulate houses and save energy. In 2024, attention to that war has waned somewhat and energy prices have fallen slightly again but are still higher than before the Russian invasion of Ukraine.

The Netherlands had large gas production because of the Groningen gas field, found in 1959 and explored from 1963, with a total of 2,800 billion m^3 natural gas. However, regional earthquakes caused by gas extraction made the Dutch government decide to stop the extraction. This decision was signed into law in 2024 [22].

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Because of the problems in the Groningen area and to take steps to follow the Paris treaty, the Dutch climate agreement included programs like *natural gas free areas*, where the government helps local communities and local governments in the transition to renewable energy in areas or districts.

We asked the respondents whether they agree that all houses need to be free from natural gas and whether all transport vehicles should be fossil fuel free. The results are presented in Figure 3.

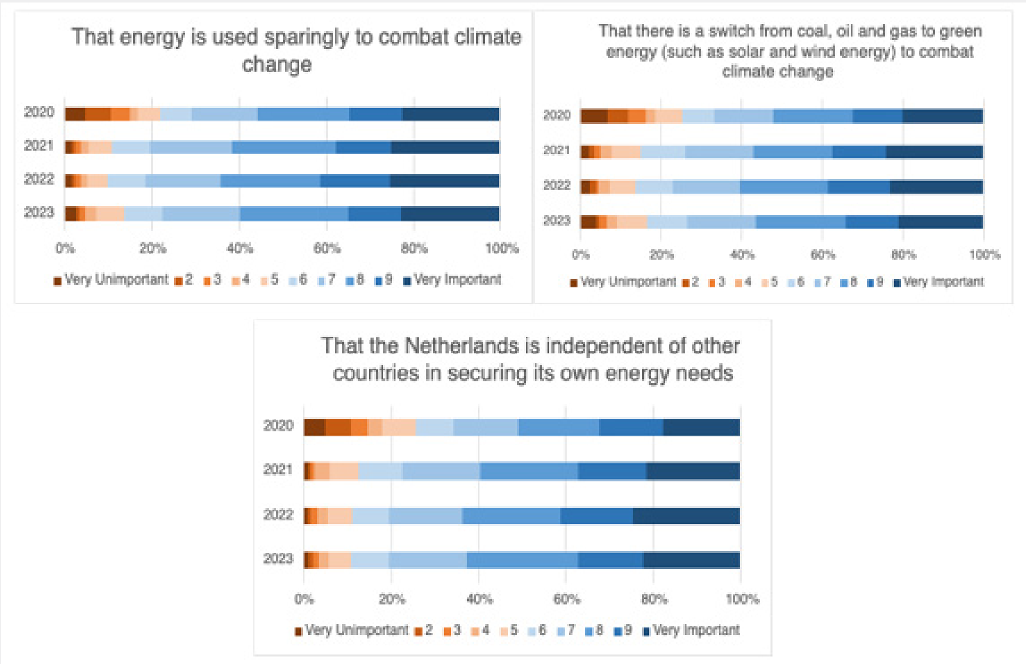

Figure 2: Responses on energy use with the general introduction: how important do you think it is…

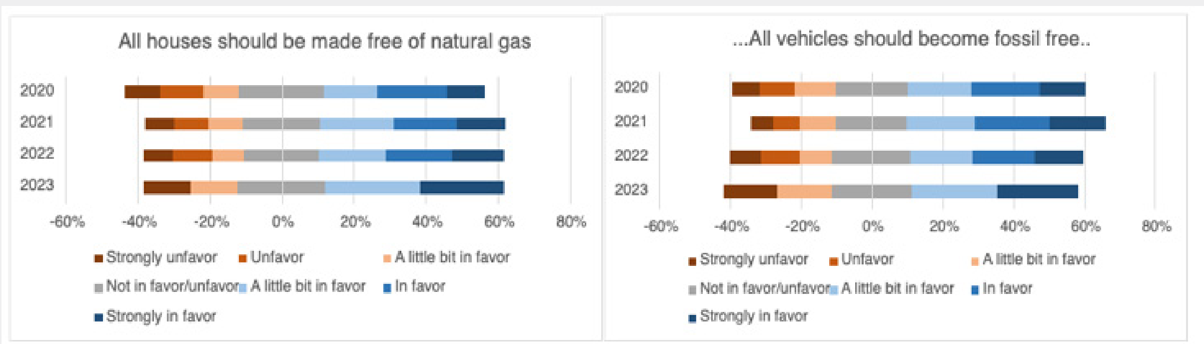

Figure 3: Attitudes of the respondents regarding natural gas free houses and fossil free cars.

In the results presented in Figure 3 the influence of the Russian invasion is visible. A majority sees the programs to get rid of natural gas for houses and fossil free cars as important, though there are some differences in the different years. Also, not everyone is happy to quit with natural gas, probably because of the costs involved in electrifying houses. Also, there is a strong minority wanting to keep diesel and gasoline vehicles, that seems to increase somewhat over time.

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Knowledge on Hydrogen

The number of news articles regarding hydrogen increased in the Netherlands over the years, is shown in Figure 4.

In all the monitors we asked the respondents knowledge questions regarding hydrogen. To prevent a learning curve among the respondents who completed the questionnaire before, each year we came forward with new items. We asked the respondents knowledge; they need to provide the correct answer (correct or incorrect). The results, percentages of good answers (correct and incorrect) are presented in Figure 5.

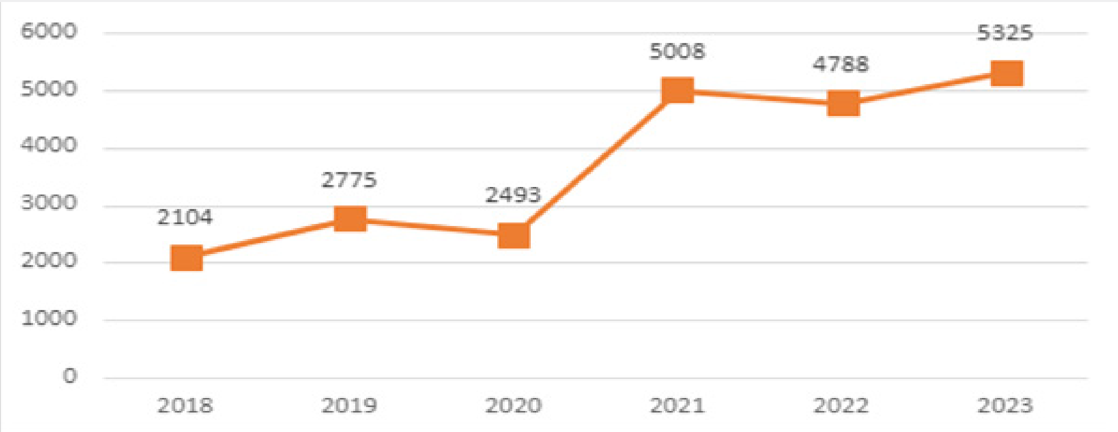

Figure 4: Hydrogen in the news (Nexis Uni, based on main Dutch newspapers).

Figure 5: Percentage of correct answers on 5 (incorrect – correct) knowledge questions regarding hydrogen.

As can be seen from Figure 5 the knowledge seems to have increased, but since we used unique items each year, we cannot make this assumption based on this data.

Self-reported knowledge on topics

We asked the respondents whether they had knowledge or know about applications (notoriety) of hydrogen in relation to various possible applications. The results are presented in Figure 5.

The results in Figure 6 might indicate that knowledge on hydrogen in the population grew but given the fact that we raised different knowledge questions we cannot make this assumption hard, since we do not know whether the questions in the different year had the same difficulty.

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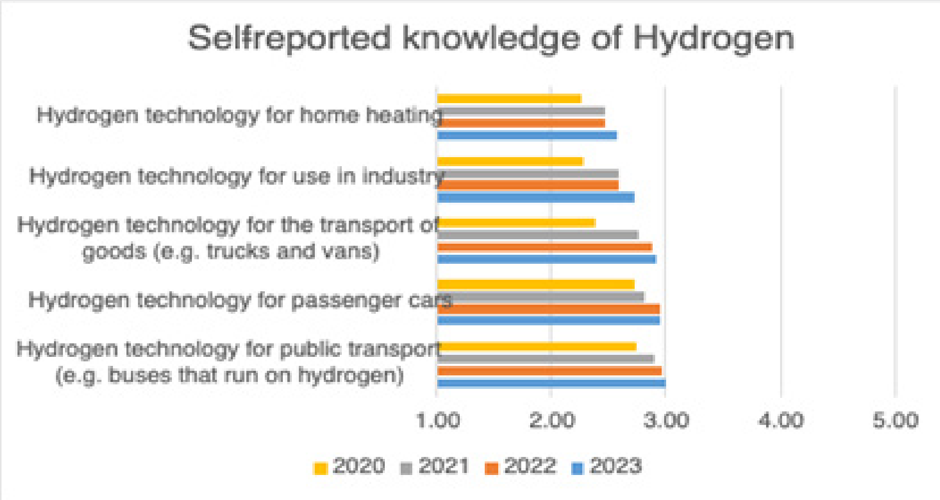

Figure 6: Indication on how often respondents were aware of hydrogen applications.

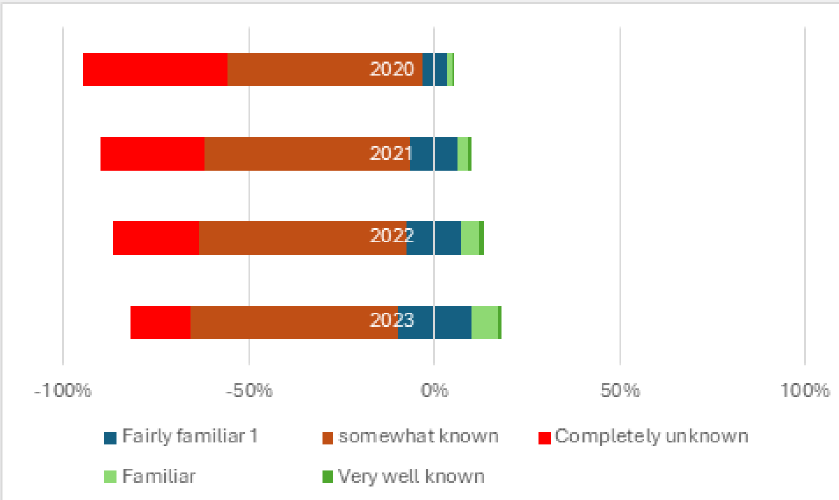

Figure 7: How do the respondents find themselves knowledgeable on hydrogen.

We also asked the respondents to rate their knowledge on hydrogen. The results are presented in Figure 7.

From Figure 6 we learn that the notoriety of hydrogen is increasing, not surprising, given the fact that hydrogen is more frequently mentioned in the news media (see Figure 4), but also that the mentioned applications are more seen in everyday life, such as for instance busses, that have large stickers placed on them indicating that they run on hydrogen.

Asked directly, how knowledgeable respondents find themselves on hydrogen can be seen in Figure 7.

In all years of the monitor, the majority see themselves not knowledgeable on hydrogen. The number of respondents that see themselves familiar and very well-known is increasing over the years.

We also asked the respondents whether they find hydrogen important for the energy transition. This question was added in the second year of the monitor, so we only have the results for the last three years. The results are presented in Figure 8.

As can be seen in Figure 8 the importance of hydrogen for the energy transition was high already in the first year, we raised this

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question (2021). A minority of less than 15% gave a rating on a ten-points scale below 6, but more than 60% scored a 6 or higher. We excluded the respondents who gave a 'don't know' as answer (19% in 2021 and 2022 and 15% in 2023).

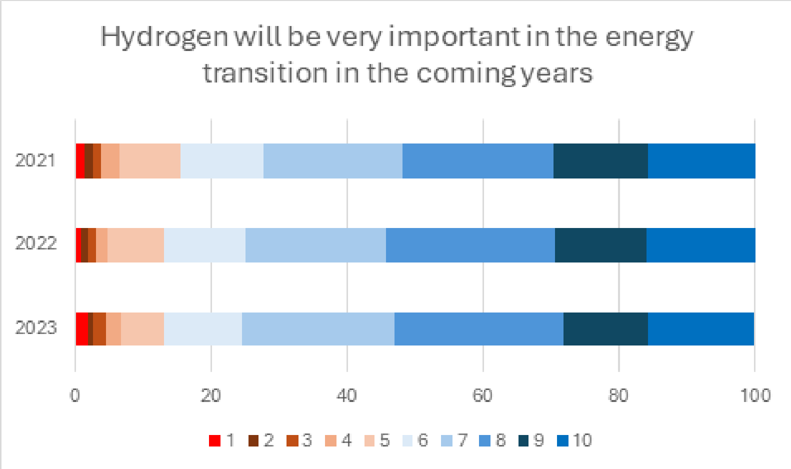

Figure 8: Importance of hydrogen for the energy transition.

At the end of the monitor, we asked the respondents to write down in own words how they felt on hydrogen. Dutch people associate hydrogen with energy, fuel, chemical gas and transport. A fifth are unfamiliar with hydrogen and there are twice as many positive associations as negative ones. The association with hydrogen is more positive than negative.

Discussion

For four years (2020 - 2023) we tested the attitude, knowledge of the Dutch population on hydrogen, using a representative panel of 1600 - 2000 respondents. The results show that the Dutch in general are more knowledgeable on hydrogen and hydrogen applications, but that the increase in knowledge does not relate to positive ratings for hydrogen. It seems that the Dutch are aware that hydrogen can play a role in the energy transition, but it is not the only solution that is needed in the energy transition. Still, most of the respondents know little on hydrogen. That might not be a big issue, because not everyone who is driving a car is able to engineer on the car. But on the other hand, when a major incident with hydrogen will occur in the future, this lack of knowledge also might turnout in lower acceptance of hydrogen, however that natural gas explosions and carbon monoxide poisonings seem not to influence the use of it. But it is important to find out which knowledge is needed and what can be done to improve the social acceptance, especially for those who work on hydrogen projects.

The lack of knowledge among the general population on hydrogen does not have to be a big issue, though we urged everyone who is developing projects that involved hydrogen to keep talking about the opportunities, but also risks involved with hydrogen.

Acceptance is determined by objective and subjective factors. The objective factors concern all the consequences of the introduction of hydrogen for society and individuals and the way in which the consequences are distributed. These factors are technical, financial-economic, legal and social in nature. Subjective, individual, psychological factors determine how people experience objective factors. This concerns values: life goals or ideals that people find important and want to pursue. Self-transcending values are primarily based on collective outcomes, focused on the well-being of other people and society or on the quality of the environment. Self-enhancing values are based on individual benefits and costs. The acceptance of energy alternatives is not just about financial arguments: people accept more expensive sustainable energy if there are other attractive consequences for the environment or climate. Trust is an important factor for social acceptance. People tend to have more confidence in parties with values that align with their own. Behavior is determined by conscious and unconscious processes. In conscious processes, decisions are made carefully based on factors such as one's own effectiveness, the sense of responsibility and the expected advantages and disadvantages. This does not happen with unconscious processes, especially in our polarized societies. Behavior can be influenced in many ways, considering conscious and unconscious processes. More knowledge does not always lead to behavioral change and behavioral intentions, nor do good intentions.

Although knowledge of hydrogen is limited, the general opinion about hydrogen technology (national and international) is positive due to confidence in the technology and concerns for the environment and the planet for the coming generation. But

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even if consumers are positive about hydrogen, this does not necessarily mean that they will use hydrogen. That also depends on the costs, technological maturity, availability and attractiveness of alternatives [23].

Whether people can demonstrate sustainable behavior is largely determined by the resources (information, time, knowledge, money) and skills (information processing, digital, network skills) they have. And because of the available practical options). About three quarters of Dutch people are open to living more sustainably, but do not do so in practice. Obstacles are often a high price (e.g. electric driving) and the availability of sustainable alternatives. But there is an important exception: the Dutch have become more energy conscious and have started working on energy savings. This is due to rising energy prices and government policy such as information, free vouchers and subsidies for solar panels and insulation [24].

Contrary to many other countries, to become fossil free, the Dutch also included natural gas, whereas other countries take the step from coal to natural gas, like Germany. In general, natural gas can initially help to reduce emissions, so natural gas can be seen as a transitional fuel from coal to renewable sources. However, its long-term use may delay the transition to renewables and contribute to sustained carbon emissions [25,26]. The unique situation in the Netherlands, where all houses have made the transition to natural gas in the sixties of last century, because of the enormous amount of natural gas found in Groningen, made that the energy transition in the Netherlands is focusing on getting rid of natural gas.

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