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The public perception of green hydrogen in the Netherlands

Report HyScaling project task 6.2

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HyScaling project and consortium

This research is part of the HyScaling project. The HyScaling consortium consists of several different partners from the high-tech manufacturing industry and knowledge institutions, and has the objective to establish a Dutch electrolyser industry and green hydrogen economy. This requires scaling up electrolyser production to increase green hydrogen production in the Netherlands. Furthermore, HyScaling aims to achieve 25-30% cost reduction for hydrogen production compared to the state-of-the-art, by bringing the project innovations to full implementation by 2030. HyScaling contributes to the establishment of a Dutch electrolyser industry and more than half of the consortium partners aim to enter the market by turning their innovations into products. These include novel components, electrolyser stacks and complete stack systems. Some partners aim at commercialization before the project ends. HyScaling is strongly market focused and use cases for green hydrogen run like a red thread through the project. The use cases connect hydrogen application to renewable power supply (from offshore wind to small-scale PV systems), creating a consistent vision of market development towards 2030. This integral description of the market aims to assure that societal contribution and public acceptance are fully embraced alongside the technological developments.

The research team would like to thank all consortium partners and consulted experts for their help and input in this study.

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Summary

S.1 Introduction

Green hydrogen can play an important role in achieving climate goals and a successful energy transition. Green hydrogen is produced by electrolysis with renewable electricity generated by e.g., sun and wind, where no CO_2 is released in the process. At the moment, green hydrogen is not yet produced with electrolysis on a large scale. A role for green hydrogen is seen mainly in the sustainable transition of high-temperature industrial processes (e.g., steel, glass and brick production), heavy transport (e.g., aviation and shipping), the production of feedstock (e.g., ammonia and methanol), storage of intermittent renewable electricity, and transport of solar and wind energy for the redistribution of those energy sources. Therefore, it is the Dutch national strategy to scale up the production, import, transport, storage, and application of green hydrogen.

A positive public perception is essential to successful upscaling of green hydrogen. However, due to societal impacts, such as increased societal costs and landscape alterations from production facilities and transport and storage infrastructure, a positive perception is not a given. Ultimately, these impacts could lead to resistance and local opposition. This can be seen as a problem because the implementation of projects can be delayed or prevented (and thus climate goals are not met), and it may be a signal of an unfair process in which local residents are not sufficiently heard.

That is why, next to technological innovation, the public perception needs to be addressed too when scaling up green hydrogen. Furthermore, green hydrogen develops at high speed and citizens are more often confronted with media outlets on hydrogen than before, and the public perception of hydrogen has only been studied to a limited extent in the Dutch context in recent years (i.e., focus on hydrogen refuelling stations, knowledge level and general opinion). Consequently, it is important to gain more insights on the public perception with recent studies. In this study we therefore assess the Dutch public perception of green hydrogen.

In order to answer the question central to this research – *What is the public perception of green hydrogen in the Netherlands?* – we aim to address the following three sub-questions:

1.1 How do people perceive green hydrogen in general?
1.2 How do people perceive several specific aspects related to green hydrogen?
1.3 What characteristics can explain the general perception of green hydrogen?

S.2 Research method

An informed questionnaire was conducted from 10 to 22 November 2023 among a representative national sample of 1594 adult Dutch citizens and a regional sample of 457 adult Dutch citizens living in the Port of Rotterdam area (a region nearby future hydrogen production facilities). In an informed questionnaire, respondents read extensive parts of balanced information that have been reviewed by experts on a certain topic, before answering questions and expressing their opinions about that topic.

S.3 Conclusions

The results show the public perception of green hydrogen is in general quite positive, both in the national and the regional sample, and before as well as after information on the topic was provided. More specifically, the public perception is also quite positive for most of the topics regarding the different parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen. Respondents perceive the role of green hydrogen in the sustainable transition of industry and in achieving climate goals as most positive. Several other topics are perceived mainly positive too: (1) placement of offshore and onshore electrolysers as production locations in the Netherlands, (2) possible consequences of green hydrogen for people and the environment, (3) the role of the Netherlands in the international hydrogen market, (4) production of green hydrogen in different countries, and (5) the ways in which green hydrogen can be stored. The ways in which green hydrogen can be transported, financial costs of hydrogen development and consequences for spatial planning in the Netherlands are perceived as least positive, but still not negative.

Although there are differences in what explains general perception at the regional and national level, for both samples trust in organizations that produce, transport, store and use hydrogen is one of the most important explanatory factors for general perception of green hydrogen. Next to trust, a positive perception of green hydrogen's role in the sustainable transition of industry, of placement of offshore and onshore electrolysers in the Netherlands, and of possible consequences of green hydrogen on people and the environment are important in explaining general perception. In addition, the results suggest that the perception of risks and benefits has a context-dependent effect on the general perception of green hydrogen, as concern about environmental and spatial consequences is a factor of importance mostly on regional level.

Moreover, we found low trust in government in general (specifically parliament and civil servants), but a prominent desired role for the government in, for example, developing a long-term strategy, creating standards (e.g., for safety and quality), and investing in research and innovation.

Upscaling green hydrogen could potentially be hindered by a lack of trust in hydrogen related organizations, and by a negative perception of increasing societal financial costs, of the consequences of green hydrogen for spatial planning in the Netherlands and a negative perception of environmental benefits, such as green hydrogen's role in the sustainable transition of industry and in achieving the climate goals.

Based on this study, we can conclude that in general, the public perception of green hydrogen in the Netherlands is quite positive. This positive perception is mainly explained by the trust the public has in organizations that produce, transport, store and use green hydrogen, and how the public perceives green hydrogen's role in the sustainable transition of industry.

S.4 Recommendations for stakeholders and practitioners

1. Invest in maintaining and building trustworthiness amongst citizens that at the moment do have trust in organizations that produce, transport, store, and use green hydrogen, while building trustworthiness amongst those citizens that do not have much trust yet. Trust in hydrogen related organizations showed as one of the most important factors for a positive perception.

2. Minimize societal financial costs and negative consequences for spatial impact, as these two aspects of green hydrogen potentially increase worries amongst the public.
3. Be alert to the way public perception is measured when assessing this as part of stakeholder or (strategic) environment management, as different measures of public perception – perception in general or the perception of specific topics related to hydrogen, such as the financial costs, spatial consequences or hydrogen's role in achieving climate goals – yield different results.

Contents

1 Introduction

1.1 Background

Green hydrogen can be one of the solutions to global warming and climate change resulting from carbon emissions (Hultman & Nordlund, 2013) and the complex technological and societal challenge of the energy transition (Scott & Powells, 2020). Hydrogen (H_2) is, at room temperature and under normal pressure, an odourless, colourless, highly flammable gas. Hydrogen is an energy carrier, i.e., a substance in which energy is stored that is released upon combustion or reaction. Hydrogen can be made in several ways. Grey hydrogen is produced with fossil fuels, such as natural gas, which releases CO_2. Currently, almost all hydrogen is produced this way. Green hydrogen is produced by electrolysis with renewable electricity generated by e.g., sun and wind. No CO_2 is released in the process. At the moment, green hydrogen is not yet produced with electrolysis on a large scale. A role for green hydrogen is seen mainly in the sustainable transition of high-temperature industrial processes (e.g., steel, glass and brick production), heavy transport (e.g., aviation and shipping), the production of feedstock (e.g., ammonia and methanol), storage of intermittent renewable electricity, and transport of solar and wind energy for the redistribution of those energy sources. Therefore, it is the Dutch national strategy to scale up the production, import, transport, storage, and application of green hydrogen (Nationaal Waterstof Programma, 2022).

A positive public perception and public acceptance of hydrogen is crucial for successful upscaling of the technology (Carr-Cornish et al., 2019; Scovell, 2022). However, public acceptance is not a given. The societal impacts, such as and increased societal costs and landscape alterations from production facilities and transport and storage infrastructure, could lead to resistance and local opposition amongst citizens (Glanz & Schönauer, 2021). These reactions are often framed as not in my backyard ('nimby'), where proximity negatively affects perception and acceptance (Glanz & Schönauer, 2021). Resistance can be seen as a problem because the implementation of projects can be delayed or prevented, and thus climate goals are not met. In addition, resistance can be a signal of an unfair process in which local residents are not sufficiently heard. The effect of lacking citizen support for green technologies has been demonstrated in the debate on, for example, wind farms (Van Halm, 2022). That is why, next to technological innovation, the public perception needs to be addressed too when scaling up green hydrogen (Huijts et al., 2019).

Although there is some insight into the perception of green hydrogen, it is important to further investigate it for several reasons. First, green hydrogen develops at high speed and citizens are more often confronted with media outlets on hydrogen than before (Van Dijk et al., 2022). Perception on hydrogen as found in earlier studies (e.g., Emodi et al., 2021; Schönauer & Glanz, 2022) cannot be ascertained a stable outcome. It is thus important to add on these insights with recent studies.

Second, there is a need to study perception of hydrogen in a more thorough way. Earlier research has measured either the perception of hydrogen technology in general (e.g., Chen et al., 2016; Lambert & Ashworth, 2018; Achterberg, 2014), or very specific applications, such as hydrogen fuel cell vehicles (e.g., Apostolou & Welcher, 2021) and hydrogen refueling

stations (e.g., Huijts et al., 2019; Huijts & van Wee, 2015). However, it is unclear to what extent this reflects the broader perception of citizens when they would get more acquainted with the technology, or when its application gets a more prominent or concrete role in people's daily lives.

Third, the public perception of hydrogen has only been studied to a limited extent in the Dutch context in recent years. For example, the Dutch public perception of hydrogen has mostly been studied with regard to hydrogen refuelling stations (Huijts et al., 2019; Huijts & van Wee, 2015). In addition, Van Dijk and colleagues (2021; 2022) and Schoonbeek and colleagues (2023) mainly focused on the level of knowledge and general opinion of Dutch citizens about hydrogen. Moreover, while several researchers point at the importance of place (Schönauer & Glanz, 2022) and proximity (Bentsen et al., 2023), the perception in Dutch regions close to (future) hydrogen production facilities has not been assessed. It is therefore important to get a better grasp of the perception of hydrogen on both the national and regional level (Baur et al., 2022).

1.2 Aim and research questions

This research aims to investigate what the general and informed public perception of green hydrogen is. Perception on specific aspects, such as spatial planning, financial costs, and goals of usage, could give more detailed insights in the public perception, additional to the current knowledge on the general perception. We investigate the public perception with an informed questionnaire, that measures general perception and perception on specific aspects of hydrogen after reading information. We hereby build further on the claim made by several researchers (e.g., De Best-Waldhober et al., 2009; Mastop et al., 2014) that opinions measured after being informed are more predictive of future opinions than uninformed opinions. Furthermore, we investigate the role of various explanatory variables of perception, such as subjective and objective knowledge, sociodemographic characteristics, value orientations, trust, and place attachment.

Central to this research is the following research question: 'What is the public perception of green hydrogen in the Netherlands?' In order to answer this question, we aim to address the following three sub-questions:

1.1 How do people perceive green hydrogen in general?
1.2 How do people perceive the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen?
1.3 What characteristics can explain the general perception of green hydrogen?

Gaining more knowledge regarding the public perception of green hydrogen is important for several reasons. It can provide more insights into an accurate picture of the public's general view on the topic and identify potential barriers for public support that may delay or prevent the implementation of green hydrogen for the purpose of reducing CO_2 emissions of Dutch industrial clusters in an early stage. In addition, involved stakeholders can use these insights in the design of participation and communication processes with local residents. Moreover, the insights can inform the ministry of Economic Affairs and Climate Policy and other involved stakeholders, such as producers of renewable electricity and possible investors in green hydrogen conversion and transport, in their choices for designing the Dutch green hydrogen economy from the perspective of society. For example, choices with regard to the locations of electricity production sites, the ownership of the hydrogen infrastructure, and priorities for hydrogen application.

1.3 Report outline

In Chapter 2 we elaborate on the literature on the public perception of (green) hydrogen and formulate expectations about potential factors that can explain perception. Chapter 3 presents the research method, including the development of the informed questionnaire. This is followed by a description of the empirical results in Chapter 4. In Chapter 5, we discuss our findings and come to conclusions by answering the research questions. In addition, based on the research findings, we give recommendations for stakeholders involved in the development of the Dutch green hydrogen economy.

2 Literature overview

This chapter presents a non-exhaustive overview of the literature on the public perception of (green) hydrogen, that has informed the empirical analysis. We first look at how hydrogen was perceived by the public as described in earlier studies. We then zoom in onto factors that can explain perception: objective and subjective knowledge, perceived risks and benefits, value orientations, place-based factors, and sociodemographic characteristics.

2.1 Public perception

In the literature, terms such as 'acceptance', 'attitude', 'opinion', 'perception', 'preferences' or 'support' are commonly used interchangeably to describe public's responses to hydrogen technologies and hydrogen related topics (Carr-Cornish et al., 2019; Huijts & van Wee, 2015). In this study, we use the term perception. Perception refers to the way in which someone "perceives, regards, understands, associates, interprets or becomes aware of something" (Emodi et al., 2021, p. 30672).

The (scientific) literature shows that the public perception of hydrogen is generally positive, with relatively high levels of support (Baur et al., 2022; Carr-Cornish et al., 2019; Oltra et al., 2017; Schönauer & Glanz, 2022). Specifically, Oltra et al. (2017) find that 60% to 70% of respondents across European countries say to support a home hydrogen fuel cell. In addition, Schönauer and Glanz (2022) find that over 60% of German citizens are positive about hydrogen as an energy carrier. This becomes lower when citizens are asked about a hydrogen pipeline to be built in their neighbourhood: 24% would be (somewhat) against it, while only 50% say they would not be against it (at all). In the Netherlands, Huijts et al. (2019) found that the evaluation of a hydrogen fuel station (by a not fully representative sample of residents living within 500 metres of the fuel station) was 3.6 on a 5-point scale before implementation, and 3.9 after implementation. Based upon these results in several countries and on, for example, hydrogen as energy carrier and hydrogen fuel stations, we expect that the general perception of hydrogen in the Netherlands is positive, too.

The perception of hydrogen can be explained by several factors, that are categorized in perceived effects (e.g., the benefits, costs and risks), and personal factors, such as knowledge, environmental awareness, value orientations, trust, and sociodemographic characteristics (e.g., education and income) (Emodi et al., 2021; Oltra et al., 2017; Schmidt & Donsbach, 2016; Scovell, 2022). We elaborate on these factors in the following paragraphs.

2.2 Knowledge

The levels of awareness and knowledge on hydrogen are generally low (Emodi et al., 2021; Ingaldi & Klimecka-Tatar, 2020; Oltra et al., 2017; Schönauer & Glanz, 2022). This is probably because of its small market share and the fact that, in general, hydrogen is not present in consumers' everyday life (Glanz & Schönauer, 2021). Although people might have a general idea of hydrogen, as they have heard about it before, there seems to be a substantial knowledge gap (Zaunbrecher et al., 2016). For example, people generally are not aware of

hydrogen as a solution for decentralized electricity storage, and have no to little knowledge about hydrogen generation, electricity generation from hydrogen, and the processes before and after hydrogen storage (Ingaldi & Klimecka-Tatar, 2020; Zaunbrecher et al., 2016).

Nonetheless, knowledge seems to play an important role in people's perception (Carr-Cornish et al., 2019; Emodi et al., 2021; Glanz & Schönauer, 2021). Subjective knowledge (the self-rated level of knowledge) influences perception of hydrogen much more than objective knowledge (the tested level of knowledge), and subjective knowledge especially influences risk perception (Huijts & van Wee, 2015; Zaunbrecher et al., 2016).

Furthermore, perception is influenced by environmental awareness and knowledge and beliefs that hydrogen technology can address environmental issues. This is particularly the case for renewable versus non-renewable hydrogen production: due to the environmental knowledge specific production methods, namely renewable energy and electrolysis, are more strongly supported, whereas the use of fossil fuels with carbon capture and storage (CCS) as an intermediate step in hydrogen production is less supported (Carr-Cornish et al., 2019; Emodi et al., 2021; Scovell, 2022).

The association of knowledge with higher acceptance, where "objective and subjective knowledge [are] indicators for positive perceptions and/or support of new energy technologies, including those associated with hydrogen" (Smith et al., 2023, p. 8371), has led to the challenged idea of the information deficit model: perception can be improved by providing adequate information. However, this association seems context- or country-dependent. While it was found that information led to a more positive perception in the UK and Australia (Bharadwaj et al., 2023; Smith et al., 2023), the opposite was found in Norway (Bentsen et al., 2023).

Research on other technologies has also demonstrated a nuanced relation between knowledge and perception. Stoutenborough and Vedlitz (2016) examined public attitudes on different energy technologies and showed that better informed members of the public are not necessarily more positive, but simply have a risk perception that is more accurate in the sense of being in line with scientific opinion. Moreover, Sütterlin and Siegrist (2017) conducted an experiment where they provided participants with information on solar radiation management to see how this would impact their perception. In this experiment, receiving a description of the technology led to a more negative perception, even when risks were not explicitly mentioned. More knowledge and information provision thus do clearly have an effect on public perception, but it is unclear whether these effects are positive or negative.

2.3 Perceived effects: benefits and risks

perceived effects of hydrogen technology, perceived benefits concern economic benefits (e.g., a positive effect on the economy), personal benefits (e.g., what people gain themselves), distributive benefits (e.g., an equal and fair distribution of benefits and burdens), and environmental benefits (e.g., the potential of addressing climate change) (Carr-Cornish et al., 2019; Emodi et al., 2021). Only a few studies looked into the perceived benefits of hydrogen as storage of energy from intermittent sources (e.g., Zaunbrecher et al., 2016). Concerns about risks relate to safety, with hydrogen being perceived as a highly explosive substance and therefore risky in its application (Baur et al., 2022; Carr-Cornish et al., 2019; Emodi et al., 2021). Existing safety precautions are usually perceived as adequate, and restraint about the technology is more related to hydrogen reliability and availability at

acceptable costs than about risks and safety (Glanz & Schönauer, 2021). We expect that perceived benefits contribute to a positive perception of green hydrogen, whereas perceived risks contribute to a more negative perception.

2.4 Value orientations

Moreover, value orientations have shown to play a role in perception and acceptance of energy technologies (De Groot et al., 2013; Perlaviciute & Steg, 2014; Scovell, 2022). Value orientations can influence several beliefs, attitudes, norms, and behaviours at the same time (De Groot & Steg, 2008; Steg & de Groot, 2012). Regarding hydrogen, people who more strongly endorse egoistic values (i.e., consider control, authority, money and possessions, working hard and being ambitious, and being influential important) possibly have stronger beliefs about economic and financial implications, and affordability and security of the energy supply. However, people who more strongly endorse biospheric values (i.e., consider protecting and respecting nature and the environment important) probably have stronger beliefs about the reduction in CO_2 emissions and impact on nature and people. As people have different value orientations that underlie their perception, it is essential to examine these values to better understand why they perceive certain aspects positively or negatively (Steg, Perlaviciute & van der Werff, 2015).

2.5 Trust in institutions and organizations

In addition, trust and credibility in government, industry and stakeholders plays an important part in public perception, and is essential for public acceptance (Baur et al., 2022; Emodi et al., 2021; Glanz & Schönauer, 2021; Huijts & van Wee, 2015; Oltra et al., 2017; Steg et al., 2015). Judgements of trust are based on the perceived competence and integrity of the involved parties (Steg et al., 2015). NGOs, universities and local stakeholders (local politicians and local investors representing local and civic interests) are generally more trusted by people than non-local stakeholders and large (energy) companies (Glanz & Schönauer, 2021). It is therefore expected that trust enhances a positive perception of green hydrogen.

2.6 Sociodemographic characteristics

Furthermore, characteristics of people can play a role in their perception (Emodi et al., 2021; Scovell, 2022). Sociodemographic characteristics such as education, age, gender and income have been shown to explain acceptance to some extent: especially younger people and men with higher education and income are more acceptant of hydrogen (Huijts & van Wee, 2015; Schönauer & Glanz, 2022).

2.7 Place-based factors

Finally, place-based factors can also play a role in people's perception, such as the location of possible future hydrogen facilities and their proximity to residential areas. The relation to a place is formed by the *place attachment*, i.e., the emotional attachment to a place, and the *place identity*, i.e., the emotions, beliefs and ideas that people associate with a place (Schönauer & Glanz, 2022; Williams & Vaske, 2003). Often, local opposition to energy

projects is framed as not in my backyard (nimby), where proximity negatively affects perception and acceptance (Glanz & Schönauer, 2021). Although a widely criticized concept because it is seen as too simplistic, nimby is still often associated with negative perception and acceptance of energy technologies. Nimby related effects, along with other concerns about landscape and environmental protection, might come into play with infrastructural changes (Glanz & Schönauer, 2021). This phenomenon has also been observed for hydrogen technology, with a decreasing level of acceptance for hydrogen infrastructure in the own neighbourhood found in a survey in Germany (Schönauer & Glanz, 2022).

Factors that could reduce negative perceptions, resistance and local opposition were found to be trust in stakeholders, as well as place-relating factors and information provision (Schönauer & Glanz, 2022). However, research in the UK points to a somewhat inverse relationship, where proximity to industrial areas with hydrogen clusters was linked to high levels of support and more distance to more conflicted opinions (Gordon et al., 2024). Therefore, there have been calls for more research clarifying community acceptance, i.e., hydrogen installations "in the proximity to where one lives" (Bentsen et al., 2023, p. 102985; Smith et al., 2023). Thus, it is still unclear how exactly proximity to future hydrogen installations influences acceptance and what the interplay with information provision could be.

All taken together and based on previous research, we expect that the perception of green hydrogen will be positive, that information and knowledge are important (but we do not know if it will contribute to a more positive perception or not), that general perception is explained by perception of several risks and benefits, that citizens' value orientations determine their support for specific hydrogen related aspects, that citizens with higher trust, younger age, higher education and income, and those who are male are more positive about green hydrogen, and that place-based factors have an effect, of which the direction is still unsure.

3 Research method

In this chapter, we describe the research method of the study. In doing so, we explain the following: the study design we used, the recruitment of respondents, including sample descriptions, how we developed and conducted the questionnaire, and which analyses we did to arrive at our results.

3.1 Study design

To identify the public perception of green hydrogen, we developed an informed questionnaire. A questionnaire enables an empirical investigation of the research questions, as it is suited to investigate the perception of a larger group of citizens and allows for a representative impression of the perception of the Dutch society. A specific form, an informed questionnaire, is used in this study. This method has derived from the methods of the informed opinion and informed choice questionnaire (e.g., De Best-Waldhober et al., 2009; Broecks et al., 2021). In an informed questionnaire, respondents read extensive parts of balanced information that have been reviewed by experts on a certain topic, before answering questions and expressing their opinions about that topic.

3.2 Participants

From 10 to 22 November 2023, I&O Research, commissioned by TNO, conducted an online informed questionnaire among a representative sample of the Dutch population regarding gender, age, educational background and region (hereafter national sample), and panel members living in the Port of Rotterdam area, a region nearby future hydrogen production facilities (hereafter regional sample).[1] A total of 2051 panel members completed the questionnaire, of which 1594 from the national sample (78%) and 457 from the Rotterdam regional sample (22%). This distinction is made to see whether there are any significant differences in the public perception of the general public and people living nearby future hydrogen production facilities. For the comparison of the demographic characteristics of both sample with the Dutch population, see Table 3.1.

[1] Panel members lived in the following villages and cities: Abbenbroek, Brielle, De Lier, Geervliet, 's-Gravenzande, Heenvliet, Hekelingen, Hellevoetsluis, Hoek van Holland, Hoogvliet Rotterdam, Honselersdijk, Maasdijk, Maasland, Maassluis, Monster, Naaldwijk, Oostvoorne, Oudenhoorn, Pernis, Poeldijk, Poortugaal, Rhoon, Rockanje, Rozenburg, Schiedam, Schipluiden, Simonshaven, Spijkenisse, Tinte, Vierpolders, Vlaardingen, Zuidland, and Zwartewaal.

Table 3.1: Gender, age, educational background, and region of residence of the national sample (n = 1594) and the regional sample (n = 457) compared with the Dutch population.

Demographic		Dutch population	National sample	Regional sample
Gender	Male	49%	55%	62%
	Female	51%	45%	38%
Age	*M*	42,4	51,1	60,7
	SD	-	17,6	15,3
Educational background	Practical	20%	21%	19%
	Intermediate	39%	37%	31%
	Theoretical	41%	42%	50%
Region of residence	North	10%	10%	-
	East	21%	23%	-
	West	45%	42%	100%
	South	24%	25%	-

3.2.1 Weighting factor

To improve the demographic representativeness of the national sample, a weighting factor was applied, based on the variables gender, educational background, age, and region of residence. This weighting factor ranged from 0.47 to 1.99. I&O Research bases the composition of Dutch society on current figures from Statistics Netherlands (CBS). The weighting factor was applied to all analyses of the national sample in order to give the most representative picture of Dutch society. For the regional sample, no weighting factor was applied.

3.3 Questionnaire development

Through interviews with hydrogen experts and HyScaling stakeholders, and a (grey) literature review, we gathered information on the green hydrogen value chain: the production, transport, storage and use. In addition, we collected information on financial costs and expected impacts and consequences of green hydrogen development, e.g., on people and the environment, spatial planning in the Netherlands, in achieving climate goals of the sustainable transition of industry. All information from the interviews and literature was rewritten into information blocks understandable for lay people, and reviewed again by hydrogen experts to ensure accuracy. For the list of all consulted experts, see Appendix A. Subsequently, we developed an informed questionnaire and incorporated the information blocks. For the full questionnaire, see Appendix B.

3.4 Procedure and measurements

The informed questionnaire started with a short introduction for respondents, clarifying the topic and aim of the research. Subsequently, the questionnaire consisted of four parts: (1) a pre-measurement of general perception and a measurement of subjective and objective knowledge, (2) information blocks on green hydrogen and related aspects, followed by

questions regarding the perception of these aspects, (3) a post-measurement of general perception, and (4) questions on respondent characteristics that may explain the perception of green hydrogen. In the following paragraphs, we elaborate on these measurements.

3.4.1 General perception before and after information

Before and after information provision, respondents were asked to indicate how they think about green hydrogen in general (Huijts et al., 2019). The question had answer categories on a five-point Likert scale ranging from 1 'very negative' to 5 'very positive', in addition to the category 'I don't know'. In addition, respondents were asked to what extent they think green hydrogen is progress and important (Huijts et al., 2019). The questions had answer categories on a five-point Likert scale ranging from 1 'totally disagree' to 5 'totally agree', in addition to the category 'I don't know'. Of the three questions before and after information, a general perception scale was constructed. The internal validity of the scale was high (before information Cronbach's α = .85; after information Cronbach's α = .90).

3.4.2 Subjective knowledge

Respondents were asked to rate their (subjective) knowledge on six aspects of green hydrogen (Huijts & van Wee, 2015), namely the advantages, disadvantages, production, transport, storage and use. The items had answer categories on a five-point Likert scale ranging from 1 'very little knowledge' to 5 'very much knowledge', in addition to the category 'I don't know'.

3.4.3 Objective knowledge

Respondents were asked to answer five factual questions about green hydrogen that measure objective knowledge (Lambert & Ashworth, 2018), such as whether green hydrogen has a smell, is flammable in air, and is available naturally in its pure form. The items had the answer categories 'yes' and 'no', in addition to the category 'I don't know'.

3.4.4 Perception of the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen

To assess the perception of green hydrogen and related aspects, respondents first read the several blocks of information, before answering the question "After reading the information, how do you think about...?". The question had answer categories on a five-point Likert scale ranging from 1 'very negative' to 5 'very positive', in addition to the category 'I don't know'. The information blocks first introduced hydrogen in general, covering what hydrogen is, how it is produced, and which contribution hydrogen can have to the energy transition. Subsequently, the information blocks introduced in ten sections the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen:

- The role of green hydrogen in achieving the climate goals;
- The role of green hydrogen in the sustainable transition of industry;
- Financial costs of green hydrogen development;

- Placement of offshore and onshore electrolysers in the Netherlands as production locations;
- Ways of transportation;
- Ways of storage;
- Consequences for spatial planning in the Netherlands;
- Possible consequences for people and the environment;
- The role of the Netherlands in the international hydrogen market;
- Production of green hydrogen in different countries.

3.4.5 Role of government in hydrogen development

Respondents were asked what their preferred role of the government in de development of green hydrogen is with the multiple choice question "What role do you think the government should take in the development of green hydrogen?" (Lambert & Ashworth, 2018). Respondents could select multiple answers, e.g., 'making laws and regulations', 'investing in research and innovation', 'provide information and education' and 'none', in addition to the answer 'other, namely'.

3.4.6 Attitude towards climate change

Attitude towards climate change was measured with a three-item scale (Kloosterman et al., 2021). An example is "I am concerned about the consequences of climate change". Respondents scored their answers on a five-point Likert scale from 1 'totally disagree' to 5 'totally agree', in addition to the category 'I don't know'. The internal validity of the scale was high (Cronbach's α = .86).

3.4.7 Attitude towards the energy transition

Attitude towards the energy transition was measured with the item "I am positive about the energy transition" (Kloosterman et al., 2021). Respondents scored their answers on a five-point Likert scale from 1 'totally disagree' to 5 'totally agree', in addition to the category 'I don't know'.

3.4.8 Value orientations

Respondents' value orientations were measured with a 17-item scale, consisting of four subscales (Bouman et al., 2018; De Groot & Steg, 2008; Steg & de Groot, 2012; Steg et al., 2014). Examples of items are "Respect nature", "Everyone is treated equally", "Doing what I like", and "Having authority over others". Following Schwartz (1992) respondents scored their answers on a nine-point scale from -1 'contrary to my values', to 0 'not important' to 7 'extremely important'. The measure by Schwartz (1992) asks respondents to rate these items on their importance as "guiding principles in their lives". For better readability, after translation the question was phrased as "Indicate for the values below to what extent this is important in your life". The internal validity of the subscales was high (biospheric Cronbach's α = .91; altruistic Cronbach's α = .88; hedonic Cronbach's α = .92; egoistic Cronbach's α = .80).

3.4.9 Place attachment

Respondents' place attachment was measured with a six-item scale (Boley et al., 2021). An example is "I strongly identify with the place where I live". Respondents scored their answers on a five-point Likert scale from 1 'totally disagree' to 5 'totally agree', in addition to the category 'I don't know'. The internal validity of the scale was high (Cronbach's α = .91).

3.4.10 Trust in hydrogen related organizations

Respondents' trust in organizations related to hydrogen was measured with four items stating different hydrogen related organizations, such as hydrogen producers and users (Huijts & van Wee, 2015; Lambert & Ashworth, 2018). Respondents scored their answers on a five-point Likert scale from 1 'no trust at all' to 5 'a lot of trust', in addition to the category 'I don't know'. The internal validity of the scale was high (Cronbach's α = .94).

3.4.11 Trust in institutions

Respondents' trust in institutions was measured with 11 items stating several different organizations, such as 'the army', 'the press', 'the parliament', and 'the scientific community' (Schmeets & Exel, 2022). Respondents scored their answers on a five-point Likert scale from 1 'no trust at all' to 5 'a lot of trust', in addition to the category 'I don't know'. The internal validity of the overall scale was high (Cronbach's α = .84). Based on the results of a principal component analysis, we also constructed subscales on 'public institutions' (judges, the press, the police, the parliament, civil servants, the European Union, and the scientific community), 'commercial institutions' (large businesses and banks) and 'classic institutions' (churches and the army). The internal validity of the 'public institutions' subscale was high as well (Cronbach's α = .87), whereas the internal validity of the 'commercial institutions' subscale was acceptable (Cronbach's α = .74) and the internal validity of the 'classic institutions' subscale was very poor (Cronbach's α = .37).

3.4.12 Open-ended question and sociodemographic variables

Lastly, a final open-ended question provided room for respondents to leave a question about or comment on the questionnaire. The sociodemographic variables age, gender, educational background, political preference, and region of residence were already known to the market research agency and coupled to the answers in the dataset.

3.5 Data analysis

The data of the informed questionnaire were statistically analysed using IBM SPSS version 28 (IBM Corp, 2021). We first carried out analyses to arrive at descriptive statistics. Subsequently, we examined a difference in means of the general perception before and after information with a paired samples *t*-test. Moreover, we examined differences in means of the perception of the ten green hydrogen related aspects with a repeated measures analysis of variance (ANOVA).

Furthermore, we examined the relationship between respondent characteristics (e.g., demographic characteristics, subjective and objective knowledge, concern about climate change, and trust in hydrogen organizations), the perception of the ten topics regarding the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen and respondents' general perception of green hydrogen.

We analysed which predictors significantly explain variance in the general perception of green hydrogen using linear regression analyses. In the regression models, the after information general perception was used as the dependent variable. We included gender, age, educational background, subjective and objective knowledge, attitudes regarding climate change and the energy transition, value orientations, place attachment, trust in institutions and hydrogen organizations, and the perception of the ten topics regarding the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen as independent variables. We searched for the strongest model, with the highest explained variance based on the R^2-value.

Finally, we approached the answers to the open-ended question qualitatively. We inductively coded the responses to the final optional open-ended question "If you have any further questions or remarks on the survey, you can mention them here" according to a number of themes: information provision on hydrogen, doubts about the feasibility of green hydrogen as an efficient solution, energy sources, safety and security concerns, and deeper transition needed. Each theme, accompanied by the number of answers in parentheses (n), is summarized in Appendix D.

4 Results

This chapter presents the results of the informed questionnaire from the national sample. The results of the regional sample can be found in Appendix C. Based on a first exploration of the data, there seemed no notable differences between the national sample and the regional sample. Therefore, the samples will not be compared, except for the scores on general perception. In addition, the qualitative results of the final open-ended question is included in Appendix D.

4.1 General perception before and after information provision

In the following paragraphs we first present the respondents' general perception before and after information provision, and the results of the paired samples *t*-test on a difference in means of the general perception before and after information. For this comparison, the three item-scales of general perception before and after information were used.

Before information was provided, almost two third of the respondents (64%; see Figure 4.1) were (very) positive about green hydrogen. Furthermore, 20% of the respondents did not know whether they are positive or negative about green hydrogen in general. After information provision, three quarters of the respondents (75%; see Figure 4.1) were (very) positive about green hydrogen. Only 2% of the respondents still did not know whether they are positive or negative about green hydrogen in general.

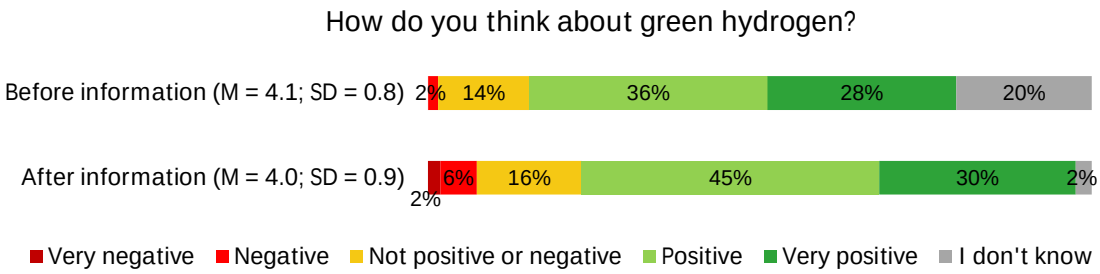

Figure 4.1: General perception of green hydrogen of the national sample before and after information (n = 1594).

Before information provision, almost two thirds of respondents (61%) thought green hydrogen is progress, whereas 21% did not know whether it is progress (see Figure 4.2). Moreover, a large majority of the respondents (81%) thought green hydrogen is important (see Figure 4.3). After information was provided, three quarters of respondents (75%) thought green hydrogen is progress (see Figure 4.2), and 69% of the respondents thought green hydrogen is important (see Figure 4.3). Still, 4% did not know whether they think green hydrogen is progress or important.

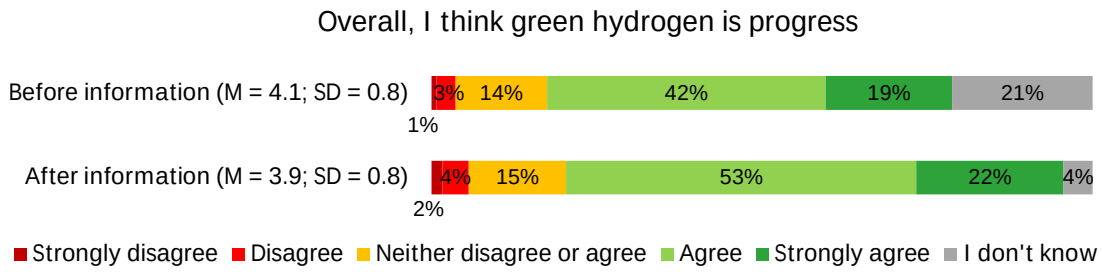

Figure 4.2: Perception of green hydrogen as progress of the national sample before and after information (n = 1594).

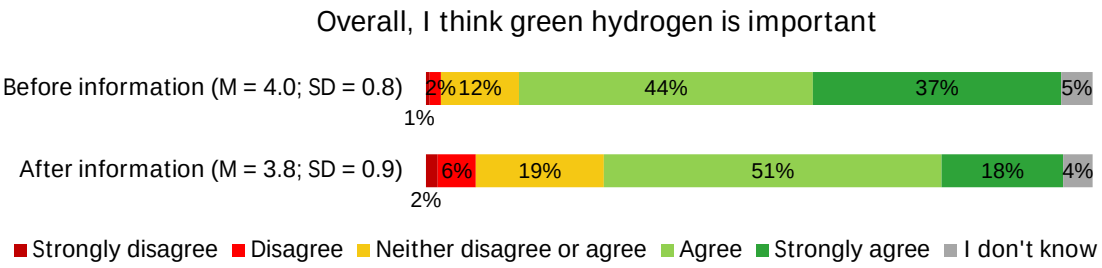

Figure 4.3: Perception of green hydrogen as important of the national sample before and after information (n = 1594).

4.1.1 Comparison of general perception before and after information

The general perception before and after information differed minimally but significantly, $t(1321) = 4.06$, $p < .001$, $d = .11$. The general perception of green hydrogen was slightly less positive after information, compared to the perception before information provision. Table 4.1 shows the means and standard deviations for the general perception before and after information.

4.1.2 Comparison of national and regional samples' general perception

The national sample and regional sample differed significantly in their general perception of green hydrogen before information was provided, $t(1733) = 2.17$, $p = .030$, $d = .12$. The respondents in the regional sample thought slightly more positive about green hydrogen in general before receiving information on the topic than respondents in the national sample. However, the two samples did not differ significantly in their general perception of green hydrogen after information was provided, $t(2017) = 1.79$, $p = .074$, $d = .09$.

4.2 Perception of the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen

In the following paragraphs we present the perception of the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen, and the results of the repeated measures analysis of variance (ANOVA) on differences in means of the perception of these topics.

After reading information on the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen, the perception of several of those topics was somewhat more positive than the perception of other topics (see Figure 4.4). A large majority of the respondents (87%) thought positively about the role of green hydrogen in the sustainable transition of industry. Likewise, 81% thought positively about the role of green hydrogen in achieving the climate goals.

In contrast, a quarter (25%) of the respondents thought negatively about the financial costs of green hydrogen development. Furthermore, 24% thought negatively about the consequences of green hydrogen for the spatial planning in the Netherlands, and 20% thought negatively about the ways green hydrogen can be transported.

For the other topics – the perception of placement of offshore and onshore electrolysers in the Netherlands as production locations, of the ways in which green hydrogen can be stored, of possible consequences for people and the environment, of the role of the Netherlands in the international hydrogen market, and of production of green hydrogen in different countries – we see somewhat divided, although mainly positive perceptions among respondents: some thought more positively about the topics than others.

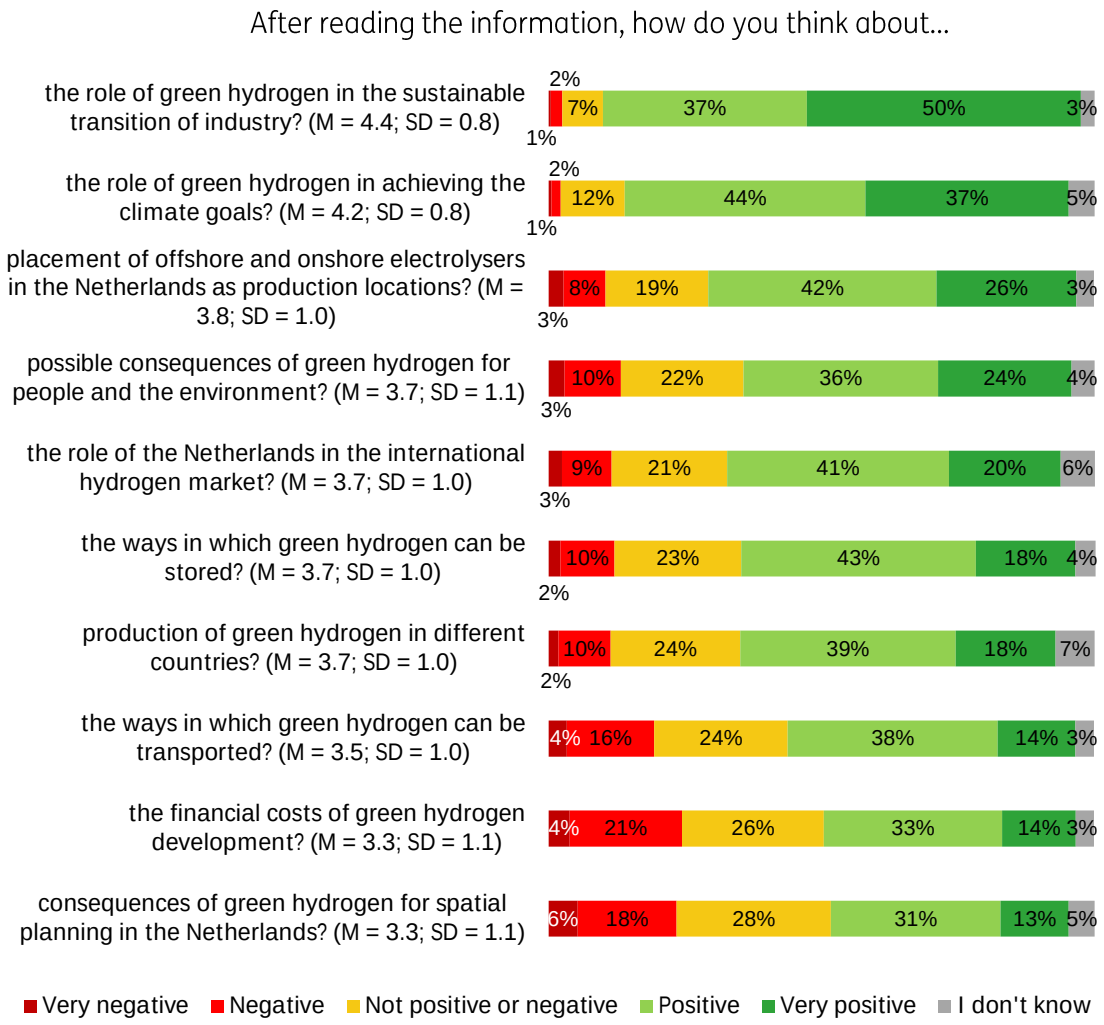

Figure 4.4: Perception of the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen of the national sample after information (n = 1594).

4.2.1 Comparison of perception of the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen

A repeated measures ANOVA was performed to compare the means of perception of the ten topics regarding the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(44) = 1116.87$, $p < .001$, and therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\varepsilon = .86$).

The means of the ten topics regarding the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen differed significantly, $F(7.7, 11193.9) = 342.47$, $p < .001$, partial $\eta^2 = .19$. A post hoc pairwise comparison using the Bonferroni correction showed there was no significant difference (ps > .471) between the perception of

- financial costs of green hydrogen development and consequences for spatial planning in the Netherlands;
- ways in which green hydrogen can be stored and
  - possible consequences for people and the environment,
  - the role of the Netherlands in the international hydrogen market,
  - production of green hydrogen in different countries;
- possible consequences for people and the environment and
  - the role of the Netherlands in the international hydrogen market,
  - production of green hydrogen in different countries;
- the role of the Netherlands in the international hydrogen market and production of green hydrogen in different countries.

All other means differed significantly from each other (ps < .007). The means and standard deviations for the perception of the ten topics regarding the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen are presented in Table 4.1.

Table 4.1: Means and standard deviations for the general perception before and after information and perception of the ten green hydrogen related aspects of the national sample (n = 1594).

Measure	*n*	*M*	*SD*
General perception of green hydrogen before information	1321	4.03	0.70
General perception of green hydrogen after information	1321	3.95	0.80
Perception of the role of green hydrogen in achieving the climate goals	1448	4.24	0.78
Perception of the role of green hydrogen in the sustainable transition of industry	1448	4.42	0.76
Perception of financial costs of green hydrogen development	1448	3.40	1.08
Perception of placement of offshore and onshore electrolysers as production locations in the Netherlands	1448	3.89	1.00
Perception of ways in which green hydrogen can be transported	1448	3.52	1.04
Perception of ways in which green hydrogen can be stored	1448	3.73	0.97
Perception of consequences for spatial planning in the Netherlands	1448	3.37	1.09
Perception of possible consequences for people and the environment	1448	3.79	1.05
Perception of the role of the Netherlands in the international hydrogen market	1448	3.76	0.99
Perception of production of green hydrogen in different countries	1448	3.72	0.97

Note. Sample sizes differ due to missing data points, i.e. the answer 'I don't know' was recoded as missing value.

4.3 Trust in hydrogen organizations and institutions

Most respondents indicated they have some or much trust in organizations that produce hydrogen (64%), organizations that transport hydrogen (59%), organizations that store hydrogen (60%), and organizations that use hydrogen (62%; see Figure 4.5). On average, 30% of respondents did not know how much trust they have in organizations that produce, transport, store and use hydrogen.

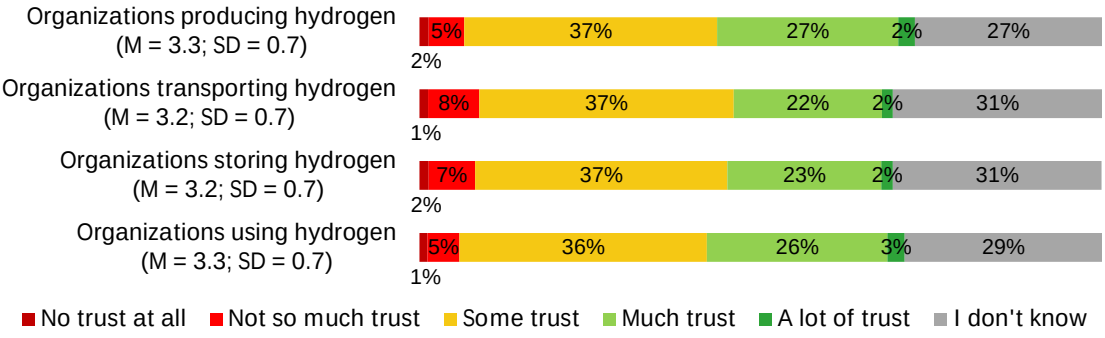

Figure 4.5: Trust in hydrogen organizations of the national sample (n = 1594).

Respondents had in general some trust in institutions such as judges, the parliament and churches. On average, respondents had much or a lot of trust (*M* = 3.1, *SD* = 0.7) in 'public institutions' (judges, the press, the police, the parliament, civil servants, the European Union, and the scientific community).[2] Most trusted were the scientific community (71%), judges (59%), and the police (56%). On the other hand, respondents had on average lower trust in 'classic institutions' (churches and the army) (*M* = 2.8, *SD* = 0.8) and 'commercial institutions' (large businesses and banks) (*M* = 2.4, *SD* = 0.8). A majority of respondents had not so much trust or no trust at all in churches (60%), large businesses (57%), and banks (51%).

4.4 Role of the government

A majority of the respondents thought the government's role in green hydrogen development should be developing a long-term strategy, creating standards (e.g., for safety and quality), ensuring good international cooperation, investing in research and innovation, making laws and regulations, and encouraging companies and industry to adopt hydrogen (see Figure 4.6). Considerably less respondents thought the government's role should be providing information and education, and encouraging consumers to adopt hydrogen. Almost none of the respondents (3%) thought the government should have no role in green hydrogen development.

[2] On a five-point Likert scale from 1 'no trust at all' to 5 'a lot of trust'.

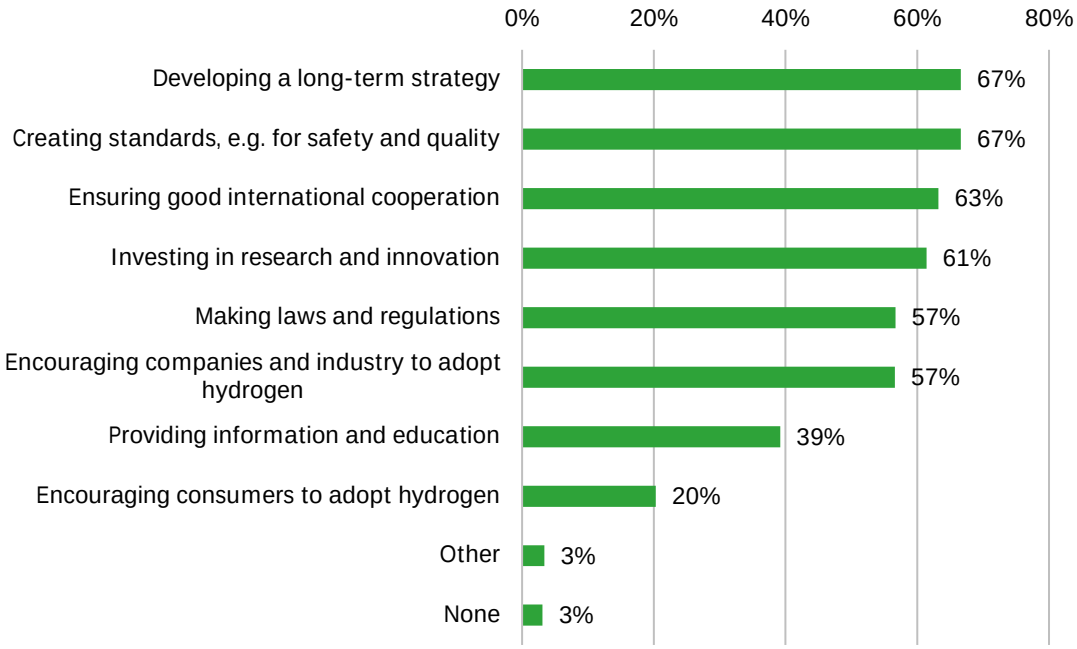

Figure 4.6: Role of the government in green hydrogen development according to the national sample (n = 1594).

4.5 Subjective knowledge

Overall, the subjective knowledge of the 1448 respondents who answered the questions was quite little. Many respondents estimated their own knowledge as (very) little on the advantages (43%), the disadvantages (56%), the production (53%), the transport (58%), the storage (61%) and the use of green hydrogen (48%). In contract, considerably less respondents estimated to have (very) much knowledge on the advantages (9%), the disadvantages (5%), the production (8%), the transport (6%), the storage (6%) and the use of green hydrogen (8%). The remaining respondents indicated to have some knowledge on these topics. On average, 11% of the respondents did not know how to estimate their knowledge on the beforementioned topics.

4.6 Objective knowledge

Respondents differed greatly in the degree of actual knowledge they have on green hydrogen: 7% answered all five questions correctly. Furthermore, 15% gave four correct answers, 21% answered three questions correctly, 19% gave a correct answer to only two questions, 13% to only one question, and 25% answered none of the questions correctly (see Figure 4.7).

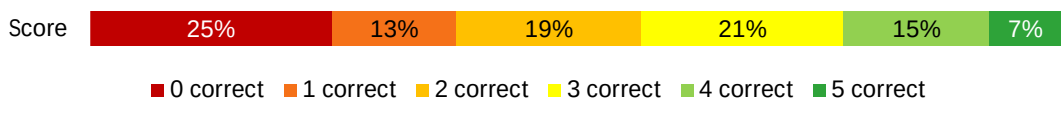

Figure 4.7: Amount of correctly answered questions by the national sample (n = 1594).

A little more than half of the respondents knew that hydrogen can be stored as a liquid (52%), and has no smell (52%). The question whether hydrogen is flammable in the air was answered correctly by 40% of the respondents. Considerably less respondents answered the questions correctly whether hydrogen is heavier than air at room temperature (25%), and whether hydrogen is available naturally in its pure form (19%).

4.7 Attitudes towards climate change and the energy transition

Respondents are in general concerned about climate change (*M* = 4.1, *SD* = 0.9).[3] A large majority of the respondents think the climate is changing (87%), and think climate change is largely caused by humans (77%). About two thirds of respondents are concerned about the effects of climate change (68%). In addition, more than two third of the respondents (70%) are positive about the energy transition (*M* = 3.9; *SD* = 1.0).[4]

4.8 Value orientations

With a high average score[5] on the biospheric value orientation (*M* = 5.1, *SD* = 1.4), respondents placed a strong emphasis on protecting and respecting nature and the environment. Moreover, the high average score on the altruistic value orientation (*M* = 4.9, *SD* = 1.3) indicated that respondents valued equality, caring for and helping others, and preventing war or conflict. Furthermore, pleasure and enjoyment were also considered important with a high average score on the hedonic value orientation (*M* = 5.0, *SD* = 1.3). On the other hand, respondents scored on average low on egoistic values (*M* = 2.0, *SD* = 1.2), suggesting that having control, authority, money and possessions, working hard and being ambitious, and being influential were less important to them.

4.9 Place attachment

Overall, respondents showed some degree of place attachment (*M* = 3.0, *SD* = 0.9).[6] In general, most respondents were attached to the place where they live (63%). However, most respondents did not agree that no other place can compare to the place where they live (59%), and disagreed on the fact that they wouldn't want to do what they do at the place where they live in any other place (61%).

[3] On a five-point Likert scale from 1 ‘totally disagree’ to 5 ‘totally agree’.
[4] On a five-point Likert scale from 1 ‘totally disagree’ to 5 ‘totally agree’.
[5] On a nine-point scale from -1 ‘contrary to my values’, to 0 ‘not important’ to 7 ‘extremely important’.
[6] On a five-point Likert scale from 1 ‘totally disagree’ to 5 ‘totally agree’.

4.10 Regression analysis on characteristics explaining the general perception of green hydrogen

In the following paragraphs we present the results of a linear regression analysis on the relationship between general perception of green hydrogen (as dependent variable) and possible explanatory measures (as independent variables).

The linear regression analysis revealed a statistically significant model, $F(24, 1001) = 105.9$, $p < .001$, adjusted $R^2 = .71$. The results showed that 71% of variance in the general perception of green hydrogen was explained by: the perception of the role of green hydrogen in achieving the climate goals, and the role of green hydrogen in the sustainable transition of industry, the perception of placement of offshore and onshore electrolysers in the Netherlands, the perception of ways in which green hydrogen can be transported, the perception of possible consequences for people and the environment, the perception of the role of the Netherlands in the international hydrogen market, the perception of production of green hydrogen in different countries, trust in institutions, trust in hydrogen organizations, and attitude towards the energy transition.

General perception was not significantly predicted by the perception of the financial costs of green hydrogen development, the perception of the ways in which green hydrogen can be stored, and the perception of consequences for spatial planning in the Netherlands. In addition, attitude towards climate change, subjective knowledge, objective knowledge, hedonic, altruistic, egoistic and biospheric value orientations, place attachment, age, educational background, and gender did not significantly explain general perception of green hydrogen.

The analysis showed that trust in hydrogen organizations, the perception of the role of green hydrogen in the sustainable transition of industry, and the perception of placement of offshore and onshore electrolysers in the Netherlands were the most important explanatory variables of general perception (see Table 4.2). When respondents had more trust in hydrogen organizations, and a more positive perception of green hydrogen's role in the sustainable transition of industry and of the placement of offshore and onshore electrolysers in the Netherlands, their general perception of green hydrogen was more positive.

These explanatory variables of general perception were followed by the perception of the role of green hydrogen in achieving the climate goals, of the role of the Netherlands in the international hydrogen market, of possible consequences of green hydrogen on people and the environment, of ways in which green hydrogen can be transported, and the perception of production of green hydrogen in different countries. The more positive respondents' perception of the beforementioned topics, the more positive their general perception of green hydrogen was. Furthermore, when respondents had a more positive attitude towards the energy transition, their general perception of green hydrogen was also more positive. On the contrary, when respondents had more trust in institutions, their general perception of green hydrogen was more negative.

Table 4.2: Regression coefficients, standard errors, betas and *p*-values for measures predicting the general perception of green hydrogen in the national sample.

Measure	B	*SE* B	β	*p*
Constant	.06	.15		.700
Trust in hydrogen organizations	.19	.03	.16	< .001
Perception of the role of green hydrogen in the sustainable transition of industry	.18	.03	.17	< .001
Perception of placement of offshore and onshore electrolysers as production locations in the Netherlands	.17	.02	.21	< .001
Perception of the role of green hydrogen in achieving the climate goals	.11	.02	.11	< .001
Perception of the role of the Netherlands in the international hydrogen market	.09	.02	.11	< .001
Perception of possible consequences for people and the environment	.09	.02	.11	< .001
Perception of ways in which green hydrogen can be transported	.07	.02	.09	< .001
Perception of countries where green hydrogen will be produced	.06	.02	.08	.002
Attitude towards the energy transition	.05	.02	.06	.010
Trust in institutions	-.10	.03	-.08	< .001
Perception of ways in which green hydrogen can be stored	.04	.02	.04	.112
Perception of consequences for spatial planning in the Netherlands	.01	.02	.02	.450
Perception of financial costs of hydrogen development	.01	.02	.01	.698
Attitude towards climate change	.03	.02	.03	.169
Subjective knowledge	.02	.02	.02	.380
Objective knowledge	.00	.01	.01	.713
Hedonic value orientation	.02	.01	.04	.072
Altruistic value orientation	-.00	.01	-.00	.880
Egoistic value orientation	-.00	.01	-.00	.942
Biospheric value orientation	-.02	.01	-.04	.149
Place attachment	.00	.02	.00	.814
Age	-.00	.00	-.01	.455
Educational background	-.01	.01	-.01	.619
Gender	-.02	.03	-.01	.600

5 Discussion and conclusions

In this chapter, we start with answering the research questions and discussing our findings on the general and informed public perception of green hydrogen, the perception of parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen, and the role of various explanatory variables of perception. In doing so, we come to our conclusions. In addition, we discuss the limitations of this study and make suggestions for follow-up research. We conclude the chapter by giving recommendations for stakeholders and practitioners involved in the development of the Dutch green hydrogen economy, based on the research findings.

5.1 Answering the research questions

5.1.1 Public perception of green hydrogen in general

In answer to the first sub-question – *How do people perceive green hydrogen in general?* – we find that the public perception of green hydrogen is in general quite positive. This is found before as well as after information on the topic was provided. This is in line with earlier studies: public perception of green hydrogen has also been found to be positive in general in Australia (Carr-Cornish et al., 2019), across seven European countries (Oltra et al., 2017), in Germany (Schönauer & Glanz, 2022), and in a not fully representative sample in the Netherlands (Huijts et al., 2019). While these studies focused on the perception in general, of application for home fuel cells, of hydrogen as an energy carrier, and of hydrogen fuel stations respectively, findings of the current study show that the positive perception is also found for the production, transport, storage, and application of green hydrogen in general.

Interestingly, we see that information does have an impact on how respondents perceive green hydrogen in general. Before information was provided 20% of the respondents did not know whether they are positive or negative about green hydrogen in general, whereas after information provision this share is only 2% of respondents. Thus, respondents shift from not knowing to having formed an opinion. Based on a further exploration of the data, we cannot say with certainty whether this shift is in the direction of a more positive or negative perception. What is clear from the results is that the amount of respondents that is negative increased with 6%, the share of respondents that are not positive or negative remained approximately the same (2% increase), and the portion of respondents that is positive increased with 11%.

5.1.2 Public perception of the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen

Furthermore, in answer to the second sub-question – *How do people perceive the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen?* – we find that the public perception is also quite positive for most of the topics

regarding the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen. When we take a closer look at these topics, we see that respondents perceive the role of green hydrogen in the sustainable transition of industry and in achieving climate goals as most positive. Several other topics are perceived mainly positive too:

- placement of offshore and onshore electrolysers as production locations in the Netherlands;
- possible consequences of green hydrogen for people and the environment;
- the role of the Netherlands in the international hydrogen market;
- production of green hydrogen in different countries;
- the ways in which green hydrogen can be stored.

Less positive, but still not very negative, is the perception of ways in which green hydrogen can be transported, financial costs of hydrogen development and consequences of green hydrogen for spatial planning in the Netherlands.

5.1.3 Characteristics that can explain the general perception of green hydrogen

In answer to the third sub-question – *What characteristics can explain the general perception of green hydrogen?* – we see that the general public perception of green hydrogen is explained by several factors. Although there are differences in what explains general perception between the national and the regional sample[7], for both samples trust in organizations that produce, transport, store and use hydrogen is one of the most important factors. If trust lacks, a positive perception is less likely. This validates earlier findings that trust matters (Baur et al., 2022; Emodi et al., 2021; Glanz & Schönauer, 2021; Huijts & van Wee, 2015; Oltra et al., 2017; Steg et al., 2015). Our study adds to this insight that it is not institutional trust (e.g., in a municipality) that matters most. Instead, it is trust specifically in organizations related to hydrogen. To our knowledge, our study is the first to identify trust in hydrogen organizations as one of the most important explanatory factors.

Interestingly, as in line with previous research (Baur et al., 2022), levels of trust in organizations related to hydrogen in both the national and regional sample were quite high: a majority of respondents (ranging from 59% to 70%) in both samples indicated to have some or much trust in organizations that produce, transport, store and use hydrogen. At the same time, a substantial part of the respondents (30% on average in the national sample, and 25% in the regional sample) did not know how much trust they have in these organizations.

Furthermore, both on national and regional level, a general positive perception of green hydrogen is explained by a positive perception of green hydrogen's role in the sustainable transition of industry. On national level, perceiving the placement of offshore and onshore electrolysers as production locations in the Netherlands, and perceiving the role of green hydrogen in achieving the climate goals positively also relates to a more positive general perception. It thus seems that perceived environmental benefits are indeed important for a

[7] Although the sociodemographic variables gender, age and educational background seemed of no importance in explaining perception of both the national and regional sample, it must be mentioned that the regional sample deviates on all three variables from the Dutch population (more theoretical educated, older males; see Table 3.1). Thus, the regional sample is not representative for the Dutch population. It is uncertain to what extent these differences significantly affect the results.

positive perception, as was suggested by earlier research (Carr-Cornish et al., 2019; Emodi et al., 2021).

On regional level, we also find that perceiving possible consequences for people and the environment and consequences for spatial planning in the Netherlands more positively, relates to a more positive perception of green hydrogen in general. Although the information on possible consequences for people and the environment mentioned that hydrogen is a highly flammable substance that can be explosive in some situations, the explanation that using green hydrogen instead of fossil fuels would be much cleaner and lead to less global warming in the long run might have been of more influence on the positive perception. Furthermore, it seems that the positive perceptions on e.g., green hydrogen's role in the sustainable transition of industry, and in achieving the climate goals outweigh the less positive perceptions of, for example, consequences for spatial planning in the Netherlands. While earlier research (Carr-Cornish et al., 2019; Emodi et al., 2021) has identified the importance of perceived economic, personal, distributive, and environmental benefits, and concerns about safety risks, this study shows that perceptions about environmental and spatial consequences is a factor of importance too. At national level the perception of environmental and spatial consequences seemed somewhat less important. These findings thus only partly support earlier findings that risk concern matters for perception (Baur et al., 2022; Carr-Cornish et al., 2019; Emodi et al., 2021).

As mentioned before, we found that, to some degree, different factors have most explanatory value in the national compared with the regional sample. This shines new light on the issue of context-dependency. Earlier studies found different results for different countries. For example, the effect of information was positive in the UK and Australia (Bharadwaj et al., 2023; Smith et al., 2023), while it was negative in Norway (Bentsen et al., 2023). The current study suggests that not only information, but also perception of risks and benefits have a context-dependent effect on perception. Moreover, these effects do not only seem to differ on country level, but also between national and regional level.

Interestingly, unlike trust in hydrogen organizations, we found that respondents have in general low trust in the government: 42% indicated to not have so much trust or no trust at all in parliament, and 37% indicated this for civil servants. At the same time, respondents foresee an important role of the government in the development of green hydrogen: between 57% and 67% of the respondents think the government's role should be developing a long-term strategy, creating standards, e.g. for safety and quality, ensuring good international cooperation, investing in research and innovation, making laws and regulations, and encouraging companies and industry to adopt hydrogen. This is a somewhat contradictory finding, as respondents expect the government to take on different roles, while at the same time they have little trust in the same government.

To answer the main question – *What is the public perception of green hydrogen in the Netherlands?* – we can conclude that in general, the public perception of green hydrogen in the Netherlands is quite positive. This positive perception is mainly explained by the trust the public has in organizations that produce, transport, store and use green hydrogen, and how the public perceives green hydrogen's role in the sustainable transition of industry, and the placement of offshore and onshore electrolysers as production locations in the Netherlands.

5.2 Implications

We learn that a lack of trust in hydrogen related organizations is a potential barrier for public support that may delay or prevent implementation of green hydrogen. In addition, when the perception of the environmental benefits, such as green hydrogen's role in the sustainable transition of industry and in achieving the climate goals or consequences of green hydrogen for people and the environment, becomes more negative, this can potentially hinder implementation.

Furthermore, in the context of public support, the less positive perceptions found in this study need to be addressed. First, this concerns the perception on the financial costs of hydrogen. Although no exact amount is known at the moment, the transition to a green hydrogen economy is very costly, part of which is funded by the national government. Second, this concerns the perception on the consequences of green hydrogen for spatial planning in the Netherlands. Although hydrogen production plants, storage sites, and pipelines will in part replace existing energy facilities, the development of green hydrogen has several implications for the way the available space is allocated and used in the Netherlands. Available space in the Netherlands is already scarce at the moment, and upscaling green hydrogen will require some of that scarce space for e.g., the wind and solar farms needed to generate electricity, electrolysers to produce hydrogen, space underground (salt caverns and empty gas fields) and above ground (storage tanks) for storage, and pipelines to transport hydrogen. When people perceive (increasing) financial support for hydrogen development from the government, and the consequences of green hydrogen for spatial planning in the Netherlands as negative, in part because this may be perceived as an unfair distribution of costs and benefits, this might lead to reduced public support of green hydrogen.

5.3 Research limitations and future research

5.3.1 Measurement of (informed) perception

This study pioneered in measuring both uninformed and informed perception. Other researchers have suggested that the informed perception is most credible (Mastop et al., 2014; de Best-Waldhober et al., 2009). As we found a small but significant difference between the measurement of general perception before and after information, it seems the result is indeed different when measuring perception with or without providing information. However, causal inference could not be made: did respondents' perception change *because* they received information? Other factors, such as the length of the questionnaire or more conscious thought about hydrogen due to the questions asked might have played a role as well. As a considerable part of respondents in this study shifted from not knowing to having formed an opinion between the two measurements, our findings suggest that information affects particularly respondents that do not know what to think of hydrogen upfront.

Moreover, the measurement of perception in this, as well as in other studies, is a snapshot, and may be subject to change over time. Therefore, more research is needed to show which measure of perception is best to predict actual public perception. To test for a causal effect of information on perception, we recommend experimental research. An experiment could contain different communication vignettes and test their effects on perception of and support for green hydrogen. To investigate whether perception indeed changes over time, longitudinal research is advised where perception is monitored over a longer period of time.

5.3.2 Respondents' understanding of information

A risk of the research method of an informed questionnaire, is that is hard to control whether respondents actually read the information and whether they do understand it. We mitigated this risk by setting a minimal reading time for respondents before they were able to move to the next question. Also, respondents with low response duration were excluded from the analysis. However, the lack of full control of reading and understanding should be kept in mind when interpreting the results.

5.3.3 Lack of detailed information on some topics

Green hydrogen development is subject to many uncertainties, for example with regard to financial costs or spatial planning. Hence, the information the respondents received in this study also contained limited details and certainties. We suggest to further investigate perception of several aspects when more information is available, for example on financial costs in terms of support from the government or consequences for spatial planning when electrolysers are placed or infrastructure is built. Previous studies have shown that the financial support for a technology and the effects of constructing a technology's infrastructure can be important determinants of the public perception of this technology (Broecks et al., 2021). The current study could be repeated when more information becomes available.

5.3.4 Differences between perceptions of topics and groups in society

As described above, different aspects matter for the general perception of the national and the regional sample. It could be hypothesized that proximity matters: one cares more about specific aspects such as consequences for spatial planning when one lives near a hydrogen production or storage site, or near infrastructure for hydrogen transport. Besides, perception was more negative on the financial costs of green hydrogen development and consequences for spatial planning. An explanation is maybe that these topics are perceived as more specific and concrete compared with more positively regarded topics, such as the role of green hydrogen in the sustainable transition of industry or in achieving climate goals. Further research into the underlying mechanisms of this variation is therefore advised. In this regard, the theory of psychological distance is worth investigating. This theory namely hypothesizes that different features become important to someone depending on the (spatial or temporal) distance one has to a certain object, a pattern that seems visible in our study too. Therefore, more research is needed in the variety in perception of the different topics studied in this research and for different groups.

5.3.5 The role of trust

As mentioned before, respondents show to have quite some trust in hydrogen organizations, but at the same time, a substantial part of the respondents do not know how much trust they have in these organizations. Nevertheless, we have not investigated in more detail what this trust is about. As trust proved to be one of the factors with most explanatory value of general perception in this study, and an important predictor of acceptance in previous research (e.g., Baur et al., 2022; Huijts & van Wee, 2015; Oltra et al., 2017), it is important to

further investigate what the trust in hydrogen organizations entails, and how it can be ensured that this trust remains sufficient.

Furthermore, we found that respondents have in general low trust in government (specifically parliament and civil servants), but foresee a prominent role for the government in, among other tasks, developing a long-term strategy, creating standards (e.g., for safety and quality), and investing in research and innovation. Follow-up research can further explore this somewhat contradictory finding on the lack of trust but desired prominent role of the government, and look more detailed into different roles of the government.

5.4 Recommendations for stakeholders and practitioners

Based on the research findings, this study leads to three main take aways for practitioners:

1. It is advised to invest in maintaining and building trustworthiness amongst citizens. Trust in organizations that produce, transport, store, and use green hydrogen showed as one of the most important factors for a positive perception in general. We found that during this study, most respondents report some degree of trust. However, three out of ten respondents also do not know yet how much they trust these organizations. With hydrogen becoming more present in the public debate and in citizens' daily lives and living areas, we expect this attitude regarding hydrogen organizations to develop quickly. This presents both a chance and a risk for organizations concerned with citizen support. If citizens that do not know yet how much trust they have will develop a trustful attitude, this can increase their support for green hydrogen. At the same time, if they develop an untrusting attitude, this negatively affects their perception and might put implementation of hydrogen technologies at risk. Investing in maintaining trustworthiness for those that at the moment do have trust, while building trustworthiness amongst those that do not have much trust yet, is therefore recommended.

2. Efforts to minimize societal financial costs and negative consequences for spatial impact are also expected to be beneficial to a positive public perception of green hydrogen. These two aspects of green hydrogen potentially increase worries amongst the public. After taking these material steps of reducing societal financial costs and negative consequences for spatial impact, we advise clear communication with citizens about the expected impacts of green hydrogen, so they can update their perception according to the newest information available.

3. When assessing the public perception as part of stakeholder or (strategic) environment management, we advise to be alert to the way this is measured. Our study shows that different measures of public perception – perception in general or the perception of specific topics related to hydrogen, such as the financial costs, spatial consequences or hydrogen's role in achieving climate goals – yield different results. Moreover, it is still unclear which measure best reflects actual perception, acceptance or intention of protest. Hence, a regional perception rate should not be leaned on as a fact. Rather it should be interpreted with knowledge of the measurement method and context.

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Appendix A
List of consulted experts

Name	Organization	Role in current research
Arend de Groot	TNO	Development information texts
Floris Taminiau	TNO	Review information texts
Gert Jan Kramer	Utrecht University (Copernicus Institute)	Review information texts
Hans van 't Noordeinde	ISPT	Review information texts
Jörg Gigler	TKI Nieuw Gas	Review information texts
Lennart van den Burg	TNO	Development & review information texts
Marcel Weeda	TNO	Development & review information texts
Marit Sprenkeling	TNO	Development information texts
Roald Suurs	TNO	Development information texts
Serge van Gessel	TNO	Review information texts
Thomas Hajonides van der Meulen	TNO	Review information texts

Appendix B
Informed questionnaire on green hydrogen

The informed questionnaire in this Appendix is the English version that was translated from the original Dutch version used in this research.

General introduction

Welcome to this questionnaire on green hydrogen developed by TNO. In this questionnaire we ask for your opinion on green hydrogen and various topics related to green hydrogen. Your opinion on this topic is important, because it partly influences the choices that are made about it in the Netherlands.

Even if you are not familiar with green hydrogen, your opinion is important. Before we ask your opinion, we first provide you with information on the subject gathered together with 9 different independent experts. The information you will see consists of a lot of text. To give you time to read everything properly, the screens remain 'fixed' for a while. You can then click through to the next page after a while.

There are no right or wrong answers. Instead, it is all about your own opinion.

Completing the questionnaire takes about 30 minutes. Much of this time is for reading information about green hydrogen and various topics related to green hydrogen. You can stop the survey at any time while completing the questionnaire.

Thank you in advance for your cooperation.

General questions

We understand that it may be difficult to answer the following questions if you do not know what green hydrogen is. We ask you to answer then from the picture you have of it. If you really have no idea, you can fill in 'I don't know'.

1. How do you think about green hydrogen?

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

2. To what extent do you agree with the statements below?

	Strongly disagree	Disagree	Neither disagree or agree	Agree	Strongly agree	I don't know

Overall, I think green hydrogen is progress	☐	☐	☐	☐	☐	☐
Overall, I think green hydrogen is important	☐	☐	☐	☐	☐	☐

3. How do you estimate your own knowledge on the topics below?

	Very little know-ledge	Little know-ledge	Some know-ledge	Much know-ledge	Very much know-ledge	I don't know
The advantages of green hydrogen	☐	☐	☐	☐	☐	☐
The disadvantages of green hydrogen	☐	☐	☐	☐	☐	☐
The production of green hydrogen	☐	☐	☐	☐	☐	☐
The transport of green hydrogen	☐	☐	☐	☐	☐	☐
The storage of green hydrogen	☐	☐	☐	☐	☐	☐
The use of green hydrogen	☐	☐	☐	☐	☐	☐

4. For the hydrogen questions below, could you please indicate what you think is the correct answer?

We are especially curious about what people currently know about the topic, so it is no problem to give a wrong answer or indicate that you don't know.

	Yes	No	I don't know
Can green hydrogen be stored as a liquid?	☐	☐	☐
Does green hydrogen have a smell?	☐	☐	☐
Is green hydrogen flammable in the air?	☐	☐	☐
Is hydrogen heavier than air at room temperature?	☐	☐	☐
Is hydrogen available in pure form in nature?	☐	☐	☐

Information blocks & questions

The following is information about green hydrogen and various topics related to green hydrogen. We understand that it is a lot of information. Nevertheless, we ask you to read the information carefully. The information is followed by a number of questions.

Introduction

To tackle global warming, we need to emit fewer greenhouse gases such as CO_2. Most of our CO_2 emissions are released when we use fossil fuels to produce electricity, for all kinds of industrial processes, as fuel for transport and for heating buildings. The Dutch government, organizations and companies therefore signed the national Climate Agreement in 2019. This contains targets to emit 55% less greenhouse gases by 2030 compared to 1990 and to emit no CO_2 at all by 2050. To achieve these goals, the coming years will be marked by an energy transition. This will involve replacing fossil fuels (such as coal, oil and natural gas) as much as possible with sustainable and low-carbon energy sources, such as solar, wind, hydropower and geothermal energy. Green hydrogen can play an important role here.

5. **After reading the information, how do you think about the role of green hydrogen in achieving the climate goals?**

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

What is hydrogen?

Hydrogen is an element abbreviated as H_2 in chemistry. At room temperature and under normal pressure, hydrogen is a gas. Hydrogen gas is the lightest gas we know, it has no smell, no colour, is non-toxic and is highly flammable. Hydrogen in pure form is almost non-existent on Earth and has to be made. Hydrogen is not an energy source, like the sun or wind, but an energy carrier. That is a substance in which energy is stored that is released upon combustion or reaction.

How can hydrogen be made?

Hydrogen can be made in several ways. Making it requires a raw material, such as natural gas or water. It also requires a lot of energy to make it, such as electricity. That energy is released again when the hydrogen is burned or reacts with oxygen. Often, a colour is mentioned when talking about hydrogen, for example grey, blue or green. This is not the colour of the hydrogen itself, as hydrogen is always colourless. The colour refers to how hydrogen is made and whether it releases CO_2 in the process. Greenhouse gas emissions depend on the energy source used in production.

Grey hydrogen is made with fossil fuels, such as natural gas. The carbon and hydrogen contained in natural gas are separated to obtain pure hydrogen. Currently, almost all hydrogen in the Netherlands and the rest of the world is made this way. Making grey hydrogen releases CO_2.

Blue hydrogen is produced in the same way as grey hydrogen, but the CO_2 produced in the process is captured and, for example, stored in an empty gas field or used as a feedstock in horticultural greenhouses. This leads to less CO_2 emissions into the air than grey hydrogen. Still, not all CO_2 is captured: this variates between 55% and 90%. Thus, some CO_2 still is released. In the Netherlands and the rest of the world, almost no blue hydrogen is made yet. It is expected that hydrogen will be produced more in this way in the coming years.

Green hydrogen is made by splitting water into hydrogen and oxygen with electricity from a renewable energy source, such as solar, wind or hydropower. This process is called electrolysis and takes place in an electrolyser. No CO_2 is released during this process. In the Netherlands and the rest of the world, green hydrogen using electrolysis is not (yet) produced. It is mainly done as a test in small quantities. Construction of the first large electrolyser on the Maasvlakte near Rotterdam recently started in the Netherlands.

What can green hydrogen contribute?

The use of hydrogen is not new. Hydrogen has been used in the Netherlands for a long time. Electrolysis technology (making hydrogen using electricity) is also over a century old. Yet this technique has not been developed very far due to the emergence of cheap natural gas in the 1970s. Currently, there are many opportunities to make electrolysis technology more efficient and cheaper. Green hydrogen therefore seems suitable for a lasting role in the Dutch sustainable energy supply.

Using electricity directly is always more efficient than converting it into hydrogen, because energy is lost in producing hydrogen with electricity. Electricity can now often be used directly as a good substitute for petrol or diesel for passenger cars, and natural gas for home heating. Hydrogen is therefore likely to play no or a minor role in the sustainable transition of cars and homes. In particular, hydrogen can be used where using electricity directly is not possible.

1. **Renewable energy for sectors** that cannot (currently) replace fossil fuels with electricity.
   - Some high-temperature **industrial processes** (such as glass, ceramic and brick production) now often use natural gas. As an energy carrier, green hydrogen can be a substitute for this natural gas.

- Hydrogen could also be important for **heavy transport**, such as aviation and shipping. Batteries would be too large and heavy to fly an aircraft or sail a cargo ship. Hydrogen may be more suitable for trucks than electricity. This still depends on developments of an efficient fuel cell that converts hydrogen into electrical energy.

2. **Renewable resources.** Hydrogen is used to make some raw materials, such as ammonia and methanol. Ammonia, for example, is needed for fertiliser production. Green hydrogen can replace the grey hydrogen currently used for this purpose. In the future, green hydrogen can also be used for e.g. iron and steel production and in the form of methanol as a feedstock in the chemical industry.

3. **Efficient use of renewable electricity.** At times when the sun shines and it is windy, there is a large supply of electricity from solar and wind power. This electricity often cannot all be used directly. However, this electricity can be used to make hydrogen. The hydrogen can be stored. During periods with little sun or wind and more demand for electricity than is generated, the hydrogen can be converted back into electricity. As electricity will be largely generated sustainably after 2030, these situations will become common and it will become more important to store or use this electricity in another form.

4. **Transporting renewable energy between countries.** Some places in the world have a shortage of renewable energy sources. In other places in the world, on the contrary, a lot of renewable electricity can be generated, for example because it is very sunny, windy or there is a lot of hydropower. Examples of these places are the Mediterranean, Norway, Chile or Australia. The electricity generated there can be converted into hydrogen and transported via ships and pipelines to locations with a shortage of renewable energy sources.

6. **After reading the information, how do you think about the role of green hydrogen in the sustainable transition of industry?**

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

What will the development of green hydrogen cost?

Making green hydrogen is currently more expensive than making or using natural gas, grey hydrogen and blue hydrogen. To make producing green hydrogen more (financially) attractive for companies, the central government is taking measures. For example, the government can tax CO_2 emissions, or give loans or subsidies to companies for improving electrolysers. For example, a small test site for electrolysers costs between €10 million and €20 million. Investments are also needed in infrastructure, such as pipelines. The total investment in green hydrogen needed from the government is expected to be billions of euros.

7. **After reading the information, how do you think about the financial costs of developing green hydrogen?**

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

Where could green hydrogen be made?

Making green hydrogen requires a lot of renewable electricity. Therefore, electrolysers are preferably built as close as possible to large wind farms or solar parks. For the Netherlands, offshore wind farms in particular are seen as the power source for electrolysers. This means that electrolysers will be built on the coast or at sea. The Netherlands could also import green hydrogen from abroad. Hydrogen will be made by commercial companies.

Green hydrogen can be made **onshore** with electrolysers along the coast. The green electricity needed for electrolysis will mainly come from offshore wind farms and be brought to the mainland via cables.

The green hydrogen will then be made at the hydrogen plant. From there, the hydrogen can be used directly or transported to other places via pipelines.

Green hydrogen can be made **at sea** with offshore electrolysers. These hydrogen plants would be on a platform in the North Sea or on a large artificial island. The hydrogen will then be made close to offshore wind farms and then taken from the offshore platform to the mainland via pipelines. From there, the hydrogen can be used directly or transported via pipelines to other places.

Green hydrogen can also be **imported** after being made abroad. This can then be transported to the Netherlands by ship or pipeline. Future investments could be made in pipelines between the Netherlands and relatively close countries, such as Portugal or Spain. Hydrogen from countries in other continents could be transported to the Netherlands via ships. Then, from Dutch ports, such as in Rotterdam and Amsterdam, the hydrogen could be transported via pipelines to other places.

8. **After reading the information, how do you think about placing electrolysers in the Netherlands (onshore, offshore) that can be used to make green hydrogen?**

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

How can green hydrogen be transported?

Hydrogen can be transported in different forms and in different ways. It is currently being investigated how this can be done safely and efficiently on a large scale.

Forms at transport

In pure form, hydrogen is a gas or liquid. Above the extremely low temperature of -253 °C, hydrogen is a **gas**, below -253 °C it is liquid. Hydrogen can be transported in gaseous form over short distances (within the Netherlands), but **liquid hydrogen** is more suitable for long-distance transport. This is because liquid hydrogen requires less space than hydrogen gas for the same amount of energy. However, it does take a lot of energy to cool hydrogen so that it becomes and stays liquid. Currently, hydrogen is only transported in liquid form on a small scale.

To transport hydrogen, it can also be bound to substances that can carry hydrogen. These are **liquid organic hydrogen carriers**, abbreviated **LOHCs**. Examples are toluene and benzene. These substances are liquid at room temperature and under ordinary pressure. This makes transport and storage easier than hydrogen gas, for example. LOHCs have limited toxicity or flammability.

Hydrogen can also be packaged into another substance, such as ammonia and methanol. **Ammonia** is best known as a raw material for fertilizers and part of detergents. Ammonia can be stored in slightly refrigerated tanks (-33°C) or at room temperature under a slight pressure of 8 to 10 bars. **Methanol** is a toxic, highly flammable form of alcohol that can carry hydrogen. Like drinkable alcohol (ethanol), methanol is a liquid that is easy to transport and store.

Before transportation, the hydrogen must first be combined with nitrogen to form ammonia, or with CO_2 to form methanol. After transportation, the hydrogen must be recovered from the ammonia or methanol. The ammonia or methanol can also be used directly as a fuel or feedstock. Ammonia and methanol are toxic substances and can be dangerous to the environment and the health of plants, animals and humans if it leaks. However, the consequences of methanol leaks are less severe than those of ammonia. Familiarity with both substances in industry is an advantage.

It takes a lot of energy to cool hydrogen gas to liquid form or convert it to a carrier (LOHC), ammonia or methanol, and also convert it back to hydrogen. This makes them expensive processes.

Pipelines and other transport

Underground pipelines can efficiently transport hydrogen over land. This can be done immediately and at any time. This network first connects industrial areas and storage sites to the (future) sites of

hydrogen production and import. Later, connections to neighbouring countries will also be built. In the long term, the natural gas pipelines already in place could also be used to transport hydrogen. However, this would require modifications to those pipelines. The pipeline network, with new pipelines and existing natural gas pipelines, will ensure sufficient ability to transport hydrogen and will increase the certainty that hydrogen can be supplied.

According to the plan of the Dutch government, HyNetwork Services, part of Gasunie, has started developing the pipeline network. HyNetwork Services will become the network operator of the pipeline network underground. In addition to this plan for the national network, it is currently studying what the local network will look like.

Pipelines in the sea may be suitable for transporting hydrogen made at sea to storage facilities offshore or onshore. They can also be used to transport hydrogen between seaside countries, such as the UK and Norway. The potential for an offshore hydrogen network is currently being explored.

In the absence of pipelines, hydrogen can also be transported in tanks by barges, trucks and trains. These ways are only suitable for transporting small quantities and to some users of hydrogen. Hydrogen for filling stations, for example, is now mostly transported via trucks.

The image shows what the Dutch government's plan for the onshore pipeline network looks like in 2030.

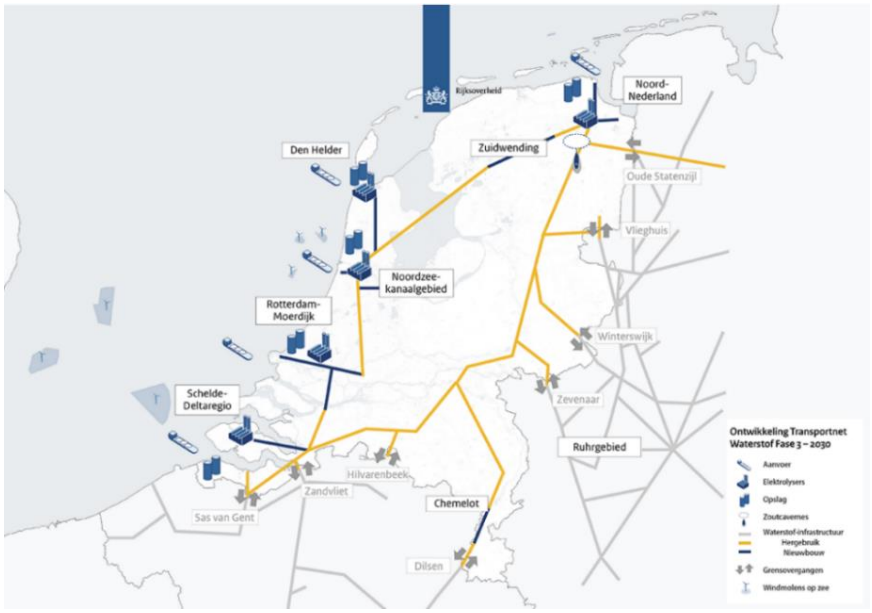

Image: hydrogen pipelines in 2030. Source: National Hydrogen Programme (2022).

9. After reading the information, how do you think about the ways in which green hydrogen can be transported?

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

How can green hydrogen be stored?

Hydrogen can be stored in different forms and in different ways. It is currently being investigated how this can be done safely and efficiently on a large scale.

If green hydrogen is increasingly used in the Netherlands, it is also necessary to store hydrogen. Storage has three functions:

- Store hydrogen that is left over temporarily for a few hours or weeks

- Store hydrogen for a few weeks to months due to changes in supply and demand through the seasons
- Store hydrogen for the long term to ensure sufficient energy

Besides short-term storage in **storage tanks** above ground, storage will mainly take place underground and in gaseous form. Empty **salt caverns** seem suitable for this purpose. These are a kind of domes in the subsurface. These storage sites are now also used to store natural gas. Until 2030, about 3 or 4 empty salt caverns are needed for hydrogen storage. After 2030, this will grow to more than 10 salt caverns. It is also being investigated whether hydrogen can additionally be stored in empty gas fields under the North Sea.

The image shows where the Dutch government's plan for 2030 identifies storage sites.

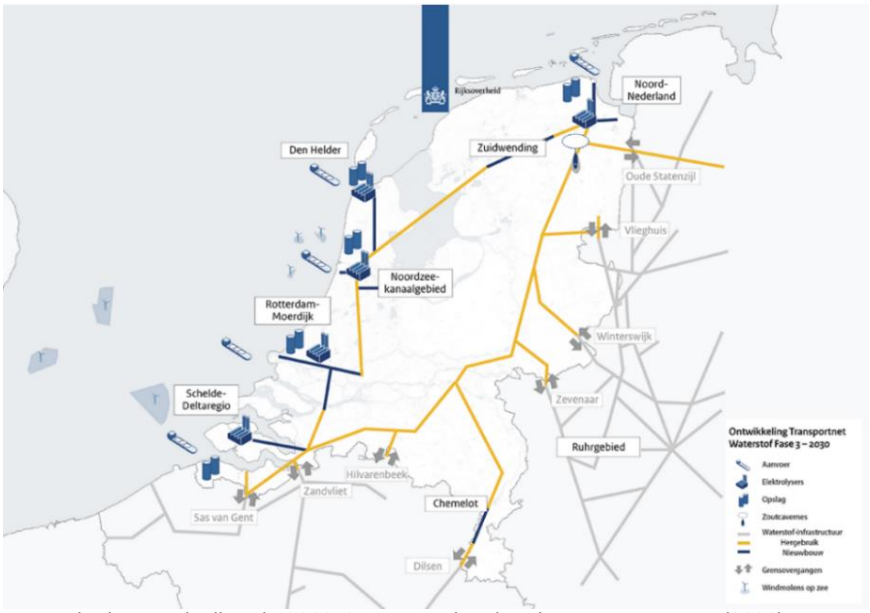

Image: hydrogen pipelines in 2030. Source: National Hydrogen Programme (2022).

10. After reading the information, how do you think about the ways in which green hydrogen can be stored?

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

What are the spatial implications of green hydrogen development?

The development of green hydrogen has several implications for the way space is allocated and used in the Netherlands. Consider, for instance, the many wind turbines and solar panels needed to generate enough electricity, and electrolysers to produce green hydrogen. Space underground (salt caverns and empty gas fields) and above ground (storage tanks) is also needed to store hydrogen. In addition, pipelines must be built to transport hydrogen, and ports adapted to import hydrogen. Sometimes hydrogen storage sites, pipelines and plants will replace existing energy facilities, such as pipelines and storage tanks for oil and natural gas.

11. After reading the information, how do you think about the consequences of green hydrogen for spatial planning in the Netherlands?

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know

☐ ☐ ☐ ☐ ☐ ☐

What are possible consequences of green hydrogen for people and environment?
Like natural gas, hydrogen is a highly flammable substance that can be explosive in some situations. Hydrogen must therefore be handled carefully to prevent it from leaking from, for example, a pipeline or storage tank. In pure gaseous form, hydrogen is not harmful to humans and the environment. That may be different for the other forms mentioned earlier, such as ammonia and liquid hydrogen. If there are clear safety standards that people adhere to, handling hydrogen in various forms will be quite safe.

Burning petrol, diesel or natural gas releases pollutants in addition to CO_2. By comparison, hydrogen combustion is clean. When hydrogen is used in a fuel cell, only hot air and water are released. One possible drawback is that when hydrogen itself leaks into the atmosphere, it can indirectly contribute to global warming. This happens because methane, a greenhouse gas just like CO_2, is less likely to break down when it comes into contact with hydrogen. Exactly how big that effect would be remains to be investigated. In any case, using green hydrogen instead of fossil fuels would be much cleaner and lead to less global warming in the long run.

12. After reading the information, how do you think about the possible consequences of green hydrogen for people and the environment?

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

What will be the role of the Netherlands in the international hydrogen market?
Hydrogen is going to play a bigger role in Europe's energy transition. This will also give the Netherlands a role in the international hydrogen market. The expected role of the Netherlands depends, for instance, on the amount of hydrogen imported by the Netherlands, organizations involved in this and trading partners.

Import volume

The more hydrogen is used, the more the Netherlands will have to produce or import its own. More own production leads to more need for wind and solar farms, especially in the North Sea. Due to the large amount of electricity required, Dutch production alone will not succeed in supplying all the hydrogen demanded in the Netherlands without becoming very expensive. Therefore, the Netherlands is also likely to import hydrogen. More imports lead to more need for import facilities and international trade relations.

Organizations involved

Companies will be importing hydrogen. The national government can ensure good conditions for imports by providing subsidies, legislating on, for example, requirements for safety and quality, and investing in relationships with potential trading partners. The International Energy Agency, an organization of 29 mainly Western countries, will have a role in monitoring the hydrogen market and hydrogen policy in Northwest Europe. Currently, an import strategy with the European Union and northern European countries is also being worked on. The role the Netherlands will have in the hydrogen market depends on European agreements and laws, for instance on hydrogen quality, and other conditions for exporting countries. By making these standards and conditions clear in a (North-West) European context, the Netherlands can make itself attractive to countries exporting hydrogen.

Trading partners

To avoid dependence on one or a few countries for hydrogen imports, the Netherlands can build import relationships with several countries. Many countries can produce and export hydrogen because natural energy sources such as sun and wind are available there. Currently, there are already alliances with Portugal, Chile, Uruguay, Namibia, Canada and the United Arab Emirates. In the future, there may also be cooperation with countries that export hydrogen, such as Saudi Arabia, Oman, Morocco,

Tunisia, Egypt, Australia, Argentina and South Africa. In addition, the Netherlands can import hydrogen from countries to which the Netherlands is linked through the European Union and international agreements. Imports are likely to be possible from Portugal, Spain, Norway and Denmark.

From 2030, a large part of the hydrogen imported by the Netherlands is expected to be further transported to Germany in particular. The Dutch ports will then be important for importing hydrogen for Northwest Europe. In doing so, the Netherlands will import and further transport sustainable fuels and raw materials for industry and other sectors. Moreover, the Netherlands can play a role in the research needed to improve, for example, electrolysis technology. This is why the Dutch government invests in research and innovation.

13. After reading the information, how do you think about the role of the Netherlands in the international hydrogen market?

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

14. After reading the information, how do you think about green hydrogen being made in the mentioned countries around the world?

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

General questions

In the next part of this survey, we will ask you a few more questions and put some statements to you. These questions and statements are about your opinion and some characteristics of yourself.

15. In general, how do you think about green hydrogen?

Very negative	Negative	Not positive or negative	Positive	Very positive	I don't know
☐	☐	☐	☐	☐	☐

16. To what extent do you agree with the statements below?

	Strongly disagree	Disagree	Neither disagree or agree	Agree	Strongly agree	I don't know
Overall, I think green hydrogen is progress	☐	☐	☐	☐	☐	☐
Overall, I think green hydrogen is important	☐	☐	☐	☐	☐	☐

17. What role do you think the government should take in the development of green hydrogen?
Multiple answers possible.

- ☐ Making laws and regulations
- ☐ Creating standards, e.g. for safety and quality
- ☐ Developing a long-term strategy
- ☐ Investing in research and innovation
- ☐ Encouraging consumers to adopt hydrogen

- ☐ Providing information and education
- ☐ Encouraging companies and industry to adopt hydrogen
- ☐ Ensuring good international cooperation
- ☐ None
- ☐ Other, namely: _____

18. To what extent do you agree with the statements below?

	Strongly disagree	Disagree	Neither disagree or agree	Agree	Strongly agree	I don't know
I think the climate is changing.	☐	☐	☐	☐	☐	☐
Climate change is largely caused by humans.	☐	☐	☐	☐	☐	☐
I am concerned about the effects of climate change.	☐	☐	☐	☐	☐	☐
I am positive about the energy transition (the transition from fossil fuels such as natural gas and coal to renewable energy such as solar and wind power).	☐	☐	☐	☐	☐	☐

19. Indicate for the values below to what extent this is important in your life. [1/4]

	Contrary to my values	Not important			Important			Very important	Extremely important
		0	1	2	3	4	5	6	7
Preventing environmental pollution.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Protecting the environment.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Respecting nature.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Being in unity with nature.	☐	☐	☐	☐	☐	☐	☐	☐	☐

20. Indicate for the values below to what extent this is important in your life. [2/4]

	Contrary to my values	Not important			Important			Very important	Extremely important
		0	1	2	3	4	5	6	7
Every person has equal opportunities.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Taking care of those who are worse off.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Every person is treated justly.	☐	☐	☐	☐	☐	☐	☐	☐	☐
There is no war or conflict.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Being helpful to others.	☐	☐	☐	☐	☐	☐	☐	☐	☐

21. Indicate for the values below to what extent this is important in your life. [3/4]

	Contrary to my values	Not important			Important			Very important	Extremely important
		0	1	2	3	4	5	6	7
Having fun.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Enjoying the life's pleasures.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Doing things I enjoy.	☐	☐	☐	☐	☐	☐	☐	☐	☐

22. Indicate for the values below to what extent this is important in your life. [4/4]

	Contrary to my values	Not important			Important			Very important	Extremely important
		0	1	2	3	4	5	6	7
Having control over others' actions.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Having authority over others.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Being influential.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Having money and possessions.	☐	☐	☐	☐	☐	☐	☐	☐	☐
Working hard and being ambitious.	☐	☐	☐	☐	☐	☐	☐	☐	☐

23. To what extent do you agree with the statements below?

	Strongly disagree	Disagree	Neither disagree or agree	Agree	Strongly agree	I don't know
I am very attached to the place where I live.	☐	☐	☐	☐	☐	☐
The place where I live is very special to me.	☐	☐	☐	☐	☐	☐
I identify strongly with the place where I live.	☐	☐	☐	☐	☐	☐
The place where I live is the best place for what I like to do.	☐	☐	☐	☐	☐	☐
No other place can compare to the place where I live.	☐	☐	☐	☐	☐	☐
What I do at the place where I live I wouldn't want to do in any other place.	☐	☐	☐	☐	☐	☐

24. Indicate how much trust you have in the organizations below. [1/2]

	No trust at all	Not so much trust	Some trust	Much trust	A lot of trust	I don't know
Churches	☐	☐	☐	☐	☐	☐
The army	☐	☐	☐	☐	☐	☐

Judges	☐	☐	☐	☐	☐	☐
The press	☐	☐	☐	☐	☐	☐
The police	☐	☐	☐	☐	☐	☐
The parliament	☐	☐	☐	☐	☐	☐
Civil servants	☐	☐	☐	☐	☐	☐
Banks	☐	☐	☐	☐	☐	☐
Large businesses	☐	☐	☐	☐	☐	☐
The European Union	☐	☐	☐	☐	☐	☐
The scientific community	☐	☐	☐	☐	☐	☐

25. Indicate how much trust you have in the organizations below. [2/2]

	No trust at all	Not so much trust	Some trust	Much trust	A lot of trust	I don't know
Organizations producing hydrogen	☐	☐	☐	☐	☐	☐
Organizations transporting hydrogen	☐	☐	☐	☐	☐	☐
Organizations storing hydrogen	☐	☐	☐	☐	☐	☐
Organizations using hydrogen	☐	☐	☐	☐	☐	☐

26. If you have any questions or comments about the questionnaire, please mention them here.

☐ No comments

Appendix C

Results of the regional sample

In this Appendix, all results of the informed questionnaire from the regional sample are presented. The results of the national sample can be found in Chapter 4 of the main report. Based on a first exploration of the data, there seemed no notable differences between the national sample and the regional sample. Therefore, the samples will not be compared, except for the scores on general perception (see paragraph 4.1.2).

C.1 General perception before and after information provision

Before information was provided, almost three quarters of the respondents (73%) were (very) positive about green hydrogen (see Figure c.1). Furthermore, 16% did not know whether they are positive or negative about green hydrogen in general. After information provision, more than three quarters of the respondents (77%) were (very) positive about green hydrogen (see Figure c.1). Only 2% of the respondents still did not know whether they are positive or negative about green hydrogen in general.

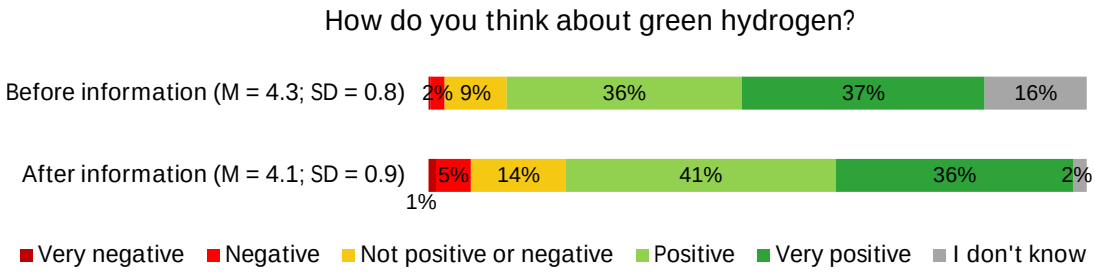

Figure C.1: General perception of green hydrogen of the regional sample before and after information (n = 457).

Before information provision, more than two third of respondents thought green hydrogen is progress (71%; see Figure c.2) and important (70%; see Figure c.3), whereas 17% did not know whether it is progress, and 16% did not know whether it is important. After information was provided, three quarters of respondents thought green hydrogen is progress (76%; see Figure c.2), and important (74%; see Figure c.3). Yet, 3% of the respondents did not know whether they think green hydrogen is progress or important.

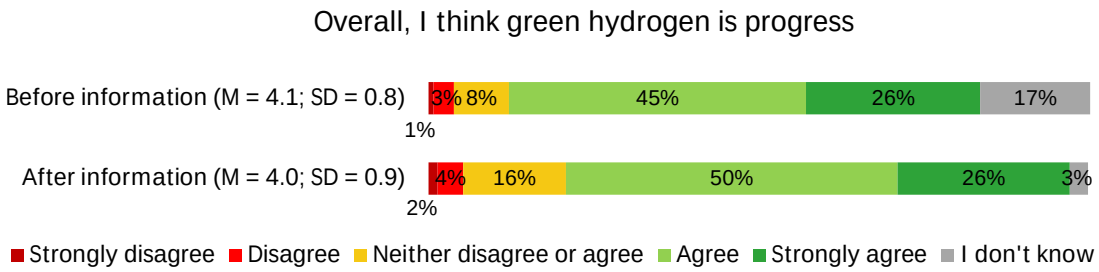

Figure C.2: Perception of green hydrogen as progress of the regional sample before and after information (n = 457).

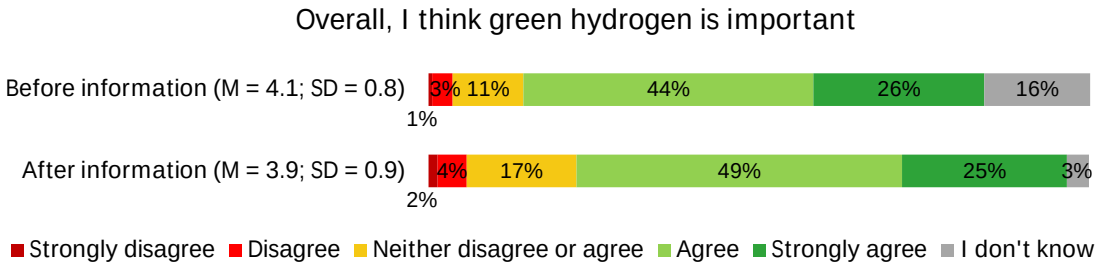

Figure C.3: Perception of green hydrogen as important of the regional sample before and after information (n = 457).

C.1.1 Comparison of general perception before and after information

The general perception before and after information did not differ significantly, $t(394) = 1.52$, $p = .130$, $d = .08$. Table c.1 shows the means and standard deviations for the general perception before and after information.

C.2 Perception of the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen

After reading information on the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen, the perception of several of those topics was somewhat more positive than the perception of other topics (see Figure c.4). A large majority of the respondents (89%) thought positively about the role of green hydrogen in the sustainable transition of industry. Likewise, 84% thought positively about the role of green hydrogen in achieving the climate goals.

In contrast, a quarter of the respondents (24%) thought negatively about the financial costs of green hydrogen development. Furthermore, 22% thought negatively about the consequences of green hydrogen for the spatial planning in the Netherlands, and 17% thought negatively about the ways green hydrogen can be transported.

For the other topics – the perception of placement of offshore and onshore electrolysers in the Netherlands as production locations, of the ways in which green hydrogen can be stored, of possible consequences for people and the environment, of the role of the Netherlands in the international hydrogen market, and of production of green hydrogen in different countries – we see somewhat divided, although mainly positive perceptions among respondents: some thought more positively about the topics than others.

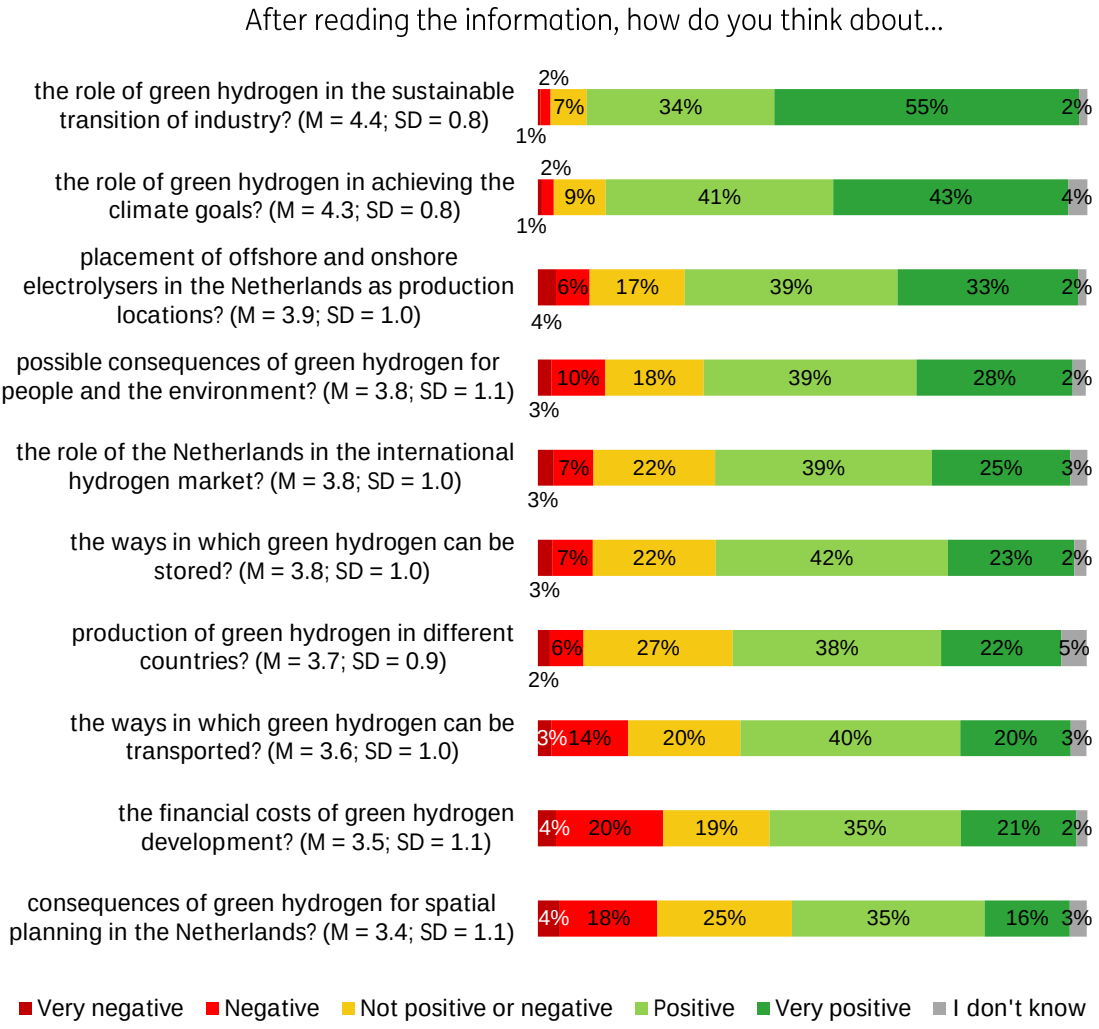

Figure C.4: Perception of the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen of the regional sample after information (n = 457).

C.2.1 Comparison of perception of the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen

A repeated measures ANOVA was performed to compare the means of perception of the ten topics regarding the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi^2(44) = 509.87$, $p < .001$, and therefore degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\varepsilon = .79$).

The means of the ten topics regarding the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen differed significantly, $F(7.1, 2886.8) = 96.90$, $p < .001$, partial $\eta^2 = .19$. A post hoc pairwise comparison using the Bonferroni correction showed there was no significant difference ($ps > .064$) between the perception of

- financial costs of green hydrogen development and
  - ways in which green hydrogen can be transported,
  - consequences for spatial planning in the Netherlands;
- placement of offshore and onshore electrolysers in the Netherlands and possible consequences for people and the environment;
- ways in which green hydrogen can be transported and
  - the role of the Netherlands in the international hydrogen market,
  - production of green hydrogen in different countries;
- ways in which green hydrogen can be stored and
  - possible consequences for people and the environment,
  - the role of the Netherlands in the international hydrogen market,
  - production of green hydrogen in different countries;
- possible consequences for people and the environment
  - the role of the Netherlands in the international hydrogen market,
  - production of green hydrogen in different countries;
- the role of the Netherlands in the international hydrogen market and production of green hydrogen in different countries.

All other means differed significantly from each other ($ps < .005$). The means and standard deviations for the perception of the ten topics regarding the parts of the value chain, financial costs and expected impacts and consequences related to green hydrogen are presented in Table c.1.

Table C.1: Means and standard deviations for the general perception before and after information and perception of the ten green hydrogen related aspects of the regional sample (n = 457).

Measure	*n*	*M*	*SD*
General perception of green hydrogen before information	395	4.13	0.72
General perception of green hydrogen after information	395	4.08	0.79
Perception of the role of green hydrogen in achieving the climate goals	409	4.28	0.80
Perception of the role of green hydrogen in the sustainable transition of industry	409	4.45	0.75
Perception of financial costs of green hydrogen development	409	3.57	1.12
Perception of placement of offshore and onshore electrolysers as production locations in the Netherlands	409	3.98	1.02
Perception of ways in which green hydrogen can be transported	409	3.66	1.05
Perception of ways in which green hydrogen can be stored	409	3.79	1.00
Perception of consequences for spatial planning in the Netherlands	409	3.45	1.10
Perception of possible consequences for people and the environment	409	3.89	1.02

Measure	*n*	*M*	*SD*
Perception of the role of the Netherlands in the international hydrogen market	409	3.81	1.00
Perception of production of green hydrogen in different countries	409	3.75	0.98

Note. Sample sizes differ due to missing data points, i.e. the answer 'I don't know' was recoded as missing value.

C.3 Trust in hydrogen organizations and institutions

Most respondents indicated they have some or much trust in organizations that produce hydrogen (70%), organizations that transport hydrogen (67%), organizations that store hydrogen (64%), and organizations that use hydrogen (68%; see Figure c.5). On average, 25% did not know how much trust they have in organizations that produce, transport, store and use hydrogen.

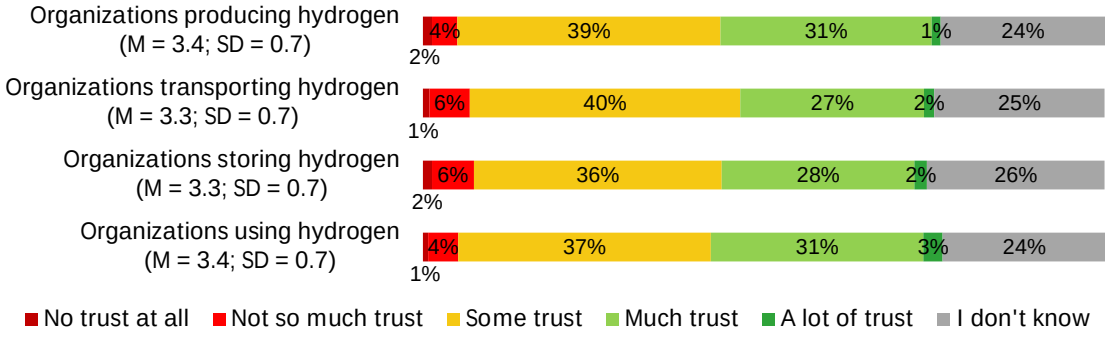

Figure C.5: Trust in hydrogen organizations of the regional sample (n = 457).

Respondents had in general some trust in institutions such as judges, the parliament and churches. On average, respondents had much or a lot of trust (*M* = 3.2, *SD* = 0.7) in 'public institutions' (judges, the press, the police, the parliament, civil servants, the European Union, and the scientific community).[8] Most trusted were the scientific community (73%), the police (65%), and judges (64%). On the other hand, respondents had on average lower trust in 'classic institutions' (churches and the army) (*M* = 2.9, *SD* = 0.8) and 'commercial institutions' (large businesses and banks) (*M* = 2.5, *SD* = 0.8). A majority of respondents had not so much trust or no trust at all in churches (56%), large businesses (53%), and banks (47%).

C.4 Role of the government

A majority of the respondents thought the government's role in green hydrogen development should be developing a long-term strategy, creating standards (e.g., for safety and quality), ensuring good international cooperation, investing in research and innovation, making laws and regulations, and encouraging companies and industry to adopt hydrogen (see Figure c.6). Considerably less respondents thought the government's role should be

[8] On a five-point Likert scale from 1 'no trust at all' to 5 'a lot of trust'.

providing information and education, and encouraging consumers to adopt hydrogen. Almost none of the respondents (1%) thought the government should have no role in green hydrogen development.

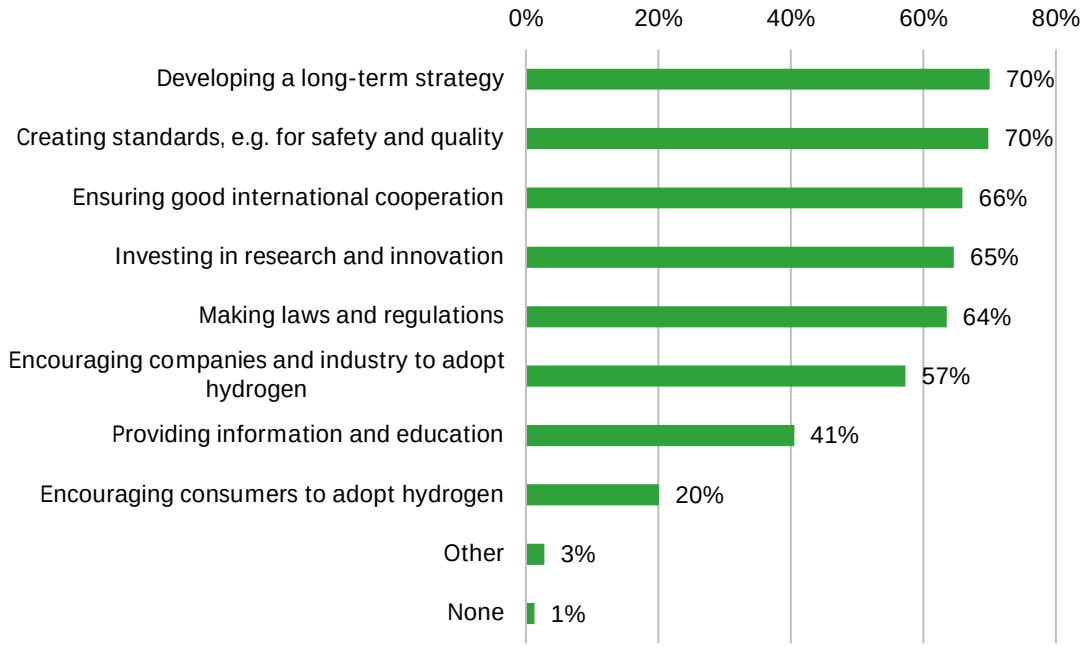

Figure C.6: Role of the government in green hydrogen development according to the regional sample (n = 457).

C.5 Subjective knowledge

The subjective knowledge of the 420 respondents who answered the questions was somewhat little. Many respondents estimated their own knowledge as (very) little on the advantages (44%), the disadvantages (48%), the production (42%), the transport (46%), the storage (48%), and the use of green hydrogen (42%). In contract, considerably less respondents estimated to have (very) much knowledge on the advantages (10%), the disadvantages (9%), the production (15%), the transport (10%), the storage (9%) and the use of green hydrogen (14%). The remaining respondents indicated to have some knowledge on these topics. On average, 9% of the respondents did not know how to estimate their knowledge on the beforementioned topics.

C.6 Objective knowledge

Respondents differed greatly in the degree of actual knowledge they have on green hydrogen: 11% of the respondents answered all five questions correctly. Furthermore, 17% gave four correct answers, 22% three, 17% two, and 13% gave one correct answer, and 20% of the respondents answered none of the questions correctly (see Figure c.7).

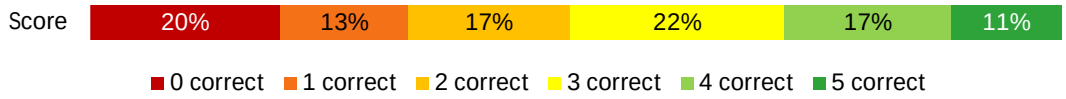

Figure C.7: Amount of correctly answered questions by the regional sample (n = 457).

More than half of the respondents knew that hydrogen can be stored as a liquid (61%), and has no smell (54%). The question whether hydrogen is flammable in the air was answered correctly by 44% of the respondents. Considerably less respondents answered the questions correctly whether hydrogen is heavier than air at room temperature (33%), and whether hydrogen is available naturally in its pure form (18%).

C.7 Attitudes towards climate change and the energy transition

Respondents are in general concerned about climate change (*M* = 4.1; *SD* = 0.8).[9] A large majority of the respondents think the climate is changing (90%), and think climate change is largely caused by humans (78%). About two thirds of respondents are concerned about the effects of climate change (71%). In addition, more than two third of the respondents (72%) are positive about the energy transition (*M* = 4.0; *SD* = 0.9).[10]

C.8 Value orientations

With a high average score[11] on the biospheric value orientation (*M* = 5.2, *SD* = 1.4), respondents placed a strong emphasis on protecting and respecting nature and the environment. Moreover, the high average score on the altruistic value orientation (*M* = 4.9, *SD* = 1.2) indicated that respondents valued equality, caring for and helping others, and preventing war or conflict. Furthermore, pleasure and enjoyment were also considered important with a high average score on the hedonic value orientation (*M* = 4.9, *SD* = 1.4). On the other hand, respondents scored on average low on egoistic values (*M* = 2.0, *SD* = 1.2), suggesting that having control, authority, money and possessions, working hard and being ambitious, and being influential were less important to them.

C.9 Place attachment

Overall, respondents showed some degree of place attachment (*M* = 2.9, *SD* = 0.9).[12] In general, most respondents were attached to the place where they live (59%). However, most respondents did not agree that no other place can compare to the place where they live (68%), and disagreed on the fact that they wouldn't want to do what they do at the place where they live in any other place (69%).

[9] On a five-point Likert scale from 1 'totally disagree' to 5 'totally agree'.
[10] On a five-point Likert scale from 1 'totally disagree' to 5 'totally agree'.
[11] On a nine-point scale from -1 'contrary to my values', to 0 'not important' to 7 'extremely important'.
[12] On a five-point Likert scale from 1 'totally disagree' to 5 'totally agree'.

C.10 Regression analysis on characteristics explaining the general perception of green hydrogen

In the following paragraphs we present the results of a linear regression analysis on the relationship between general perception of green hydrogen (as dependent variable) and possible explanatory measures (as independent variables).

The linear regression analysis revealed a statistically significant model, $F(24, 291) = 49.9$, $p < .001$, adjusted $R^2 = .79$. The results showed that 79% of variance in the general perception of green hydrogen was explained by: the perception of the role of green hydrogen in the sustainable transition of industry, the perception of placement of offshore and onshore electrolysers in the Netherlands, the perception of consequences for spatial planning in the Netherlands, the perception of possible consequences for people and the environment, subjective knowledge, trust in hydrogen organizations, and attitude towards climate change.

General perception was not significantly predicted by the perception of the role of green hydrogen in achieving the climate goals, the perception of financial costs for hydrogen development, the perception of the ways in which green hydrogen can be transported, and stored, the perception of the role of the Netherlands in the international hydrogen market, and the perception of production of green hydrogen in different countries. In addition, objective knowledge, trust in institutions, altruistic, egoistic, hedonic and biospheric value orientations, attitude towards the energy transition, place attachment, gender, educational background and age did not significantly predict general perception of green hydrogen.

The most important explanatory variables of general perception were trust in hydrogen organizations, the perception of green hydrogen's role in the sustainable transition of industry and the perception of possible consequences of green hydrogen on people and the environment (see

table c.2). When respondents had more trust in hydrogen organizations, and a more positive perception of green hydrogen's role in the sustainable transition of industry and of possible consequences of green hydrogen on people and the environment, their general perception of green hydrogen was more positive.

These explanatory variables of general perception were followed by the perception of placement of offshore and onshore electrolysers in the Netherlands, subjective knowledge, and the perception of consequences for spatial planning in the Netherlands. The more positive respondents' perception of the beforementioned topics, or the more respondents thought they know about green hydrogen, the more positive their general perception of green hydrogen was. In addition, respondents' perception of green hydrogen was more positive when they were more concerned about climate change.

Table C.2: Regression coefficients, standard errors, betas and p-values for measures predicting the general perception of green hydrogen in the regional sample.

Measure	B	*SE* B	β	*p*
Constant	-.24	.25		.346
Trust in hydrogen organizations	.29	.05	.23	< .001
Perception of the role of green hydrogen in the sustainable transition of industry	.21	.05	.20	< .001
Perception of possible consequences for people and the environment	.16	.03	.20	< .001
Perception of placement of offshore and onshore electrolysers as production locations in the Netherlands	.11	.04	.14	.002
Perception of consequences for spatial planning in the Netherlands	.09	.04	.12	.019
Subjective knowledge	.10	.03	.11	.003
Attitude towards climate change	.10	.04	.10	.010
Perception of the role of the Netherlands in the international hydrogen market	.06	.04	.07	.125
Perception of ways in which green hydrogen can be stored	.05	.04	.07	.205
Perception of the role of green hydrogen in achieving the climate goals	.04	.04	.04	.318
Perception of financial costs of hydrogen development	.02	.03	.03	.457
Perception of ways in which green hydrogen can be transported	.00	.04	.00	.956
Perception of countries where green hydrogen will be produced	-.02	.03	-.02	.647
Trust in institutions	-.08	.05	-.06	.106
Attitude towards the energy transition	-.01	.04	-.02	.700
Objective knowledge	.01	.02	.03	.410
Altruistic value orientation	.04	.02	.05	.142
Egoistic value orientation	.02	.02	.04	.236
Hedonic value orientation	.01	.02	.01	.757
Biospheric value orientation	-.02	.02	-.04	.300
Place attachment	-.04	.03	-.04	.132
Gender	.07	.05	.04	.224
Educational background	.02	.02	.03	.325
Age	-.00	.00	-.05	.097

Appendix D
Qualitative answers to open-ended question

In total, 210 respondents left a comment at the end of the questionnaire. Many complemented or critiqued the readability, length, and questions asked, but there were also a few substantive comments regarding the topic of green hydrogen. Hereafter, five main themes within these comments are identified. Note that these data are not representative, but can still provide insight into people's opinions and possibly overlooked issues.

Information provision on hydrogen (57 comments): The most commonly shared comment was that participants see hydrogen as a very interesting topic, were thankful for the information provided and had the feeling they learned a lot (32). However, many also mentioned that they thought the topic was quite difficult (16) and some thought there was still too much uncertainty to really form an opinion (9). Thus, citizens seem to be interested in information provision, but it should be taken into account that the provided information can be difficult to understand for laypeople and content should be adapted accordingly, depending on the audience.

Doubts about the feasibility of green hydrogen as an efficient solution (34 comments): Many still see energy loss and lack of efficiency as a key problem (13). There are also doubts about whether hydrogen is really green (6) and whether it can be a distraction from currently available solutions such as direct electrification (4). Moreover, the target date of 2030 is seen as unrealistic by some (5) and some are worried about the costs (6). Clear communication on the relation between green hydrogen and electrification, and how they can work in synergy seem important.

Energy sources (26 comments): many missed a mention of nuclear energy (16) and see it as a good way to produce hydrogen (3). Some are not against hydrogen, but against a further expansion of wind energy (and solar energy, to a lesser extent) (7). Hence, it is important to pay attention to the associations of green hydrogen with certain energy sources and how this can affect people's acceptance of the technology.

Safety and security concerns (17 comments): hydrogen is perceived as dangerous and unsafe (11), e.g., due to its explosiveness ("knalgas"), but also due to false associations with the hydrogen bomb. Moreover, there are concerns about hydrogen installations in the North Sea and on the coast, and in how far these could be appropriately protected from attacks (5). Concerns on safety and security still seem to play a role, and these concerns thus need to be addressed.

Further transition needed (9 comments): some participants were sceptical of what they perceived as technical solutions such as hydrogen, and stated that environmental problems require a further ecological transition, less consumption, and a change of mindset (5). Other participants also stated a distrust in market solutions and for-profit businesses to lead a hydrogen economy, instead they confided more strongly in the government (4). While this was mentioned by fewer respondents, and concerns the energy transition in general more than hydrogen specifically, scepticism towards technological fixes and market solutions can be a major barrier to the implementation of green hydrogen as currently envisioned.

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