Sociotechnical Imaginaries of Green Hydrogen Energy Storage

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Table of Contents

Preface 5
Executive Summary 6
1. Introduction 7
  1.1. Relevance to Management of Technology 9
2. Theory Section 10
3. Research Design & Method 12
  3.1. Research Design 12
  3.2. Research Method 12
4. Results 17
  4.1. Concourse Development 17
  4.2. Factor Extraction and Rotation 19
  4.3. Factor Interpretation 19
5. Discussion 26
  5.1. Practical Recommendations 28
  5.2. Theoretical Implications 30
  5.3. Limitations and Further Research 31
6. Conclusion 33
7. Reflection 34
Reference list 35
Appendices 39
  1. Appendix – Statements 39
  2. Appendix – Respondent Loadings on Factors 41
  3. Appendix – Sort Values 43
  4. Appendix – Crib Sheets 45
    4.1. Crib Sheet Factor 1 45
    4.2. Crib Sheet Factor 2 47
    4.3. Crib Sheet Factor 3 49
    4.4. Crib Sheet Factor 4 51
    4.5. Crib Sheet Factor 5 53
  5. Appendix – Invitation Email Format 55
  6. Appendix – Condition of Instructions 56

List of Figures

Figure 1 – The stages of Q process (Damio, 2016) 13
Figure 2 – A example Q grid from the software used 14
Figure 3 – Flow diagram of the selection process (based on Doorn, 2021) 17
Figure 4 - Different policy pathways (Wanzenböck et al., 2020) 29

List of Tables

Table 1 – Overview of the articles used for concourse development 17
Table 2 - Initial factor information 19
Table 3 - Respondent loading with 6 factors extracted 19
Table 4 - Respondent loading with 5 factors extracted 19
Table 5 - Division of loading and not loading respondents per professional role 20
Table 6 - Distinguishing statements for factor 1 20
Table 7 - Distinguishing statements for factor 2 21
Table 8 - Distinguishing statements for factor 3 22
Table 9 - Distinguishing statements for factor 4 22
Table 10 - Distinguishing statements for factor 5 23
Table 11 - Factor correlation matrix 24
Table 12 - Average correlation 24

Abbreviations

Abbreviation	Meaning
STS	Science and Technology Studies
GHG	Greenhouse Gasses
GHES	Green Hydrogen Energy Storage
MoT	Management of Technology
QMS	Q Method Software
PCA	Principal Component Analysis
CFA	Centroid Factor Analysis
SDG	Sustainable Development Goals

Preface

The desire to write on climate change mitigating technologies stems from personal concern for our planet's future in combination with a background as a mechanical engineer. Being 25 years old, I will personally experience the consequences of a climate which warms past 2 degrees Celsius. In my perspective, it is not all grim. My concern for our climate is countered by my enthusiasm for engineering solutions like Green Hydrogen Energy Storage. Genuine excitement can take over when this technology/energy carrier is discussed or when I read on hydrogen in general. I would like to thank Martijn Wiarda, Neelke Doorn, Geerten van de Kaa and Toyah Rodhouse for guiding me during this research thesis. Communication has been incredibly enjoyable and when I had questions, they were more than happy to meet or respond and thus make lot of time for me. It has been a privilege to cooperate with and learn from these immensely competent and experienced academics.

Executive Summary

In order to combat the global climate crisis, our energy provision needs to be decarbonized. One of the potential methods that can help is Green Hydrogen Energy Storage (GHES). GHES is a complex technology/energy carrier combination. It comprises of a conversion process of renewable electricity to hydrogen to then be used for conversion back to electricity at times of high electricity demand and low renewable supply e.g., in winter. Describing sociotechnical imaginaries on this technology/energy carrier combination can provide better alignment of the technology/energy carrier combination with the normative ideas of actors & stakeholders. The research question is thus formulated as: "What are the different sociotechnical imaginaries of green hydrogen energy storage (GHES) in the Netherlands?" These sociotechnical imaginaries will be described by using Q method. The scientific relevance is twofold. First, insight into the conflicting and overlapping imaginaries on this topic. Second, methodological because Q method is relatively new for studying sociotechnical imaginaries. The master Management of Technology is organized around technology, innovation, organization, commercialization, engineering economics, research, and reflection. Research and reflection are by design embedded in this research thesis and technology and innovation are connected because the aim of the thesis is to describe the sociotechnical imaginaries of GHES in the Netherlands and to have that knowledge be utilized by the stakeholders to better align the technology to the sociotechnical imaginaries. And finally, organization relates to the industry stakeholders who will be aware of desired technology futures and can innovate towards those desired futures. The imaginaries have been named: [1] "We are hydrogen-optimistic and critically realistic", [2] "Hydrogen: a driver for economic opportunity", [3] "We're not excited", [4] "Welcome state intervention", and [5] "Hydrogen storage is the way to go but be aware of big industry". The first imaginary mainly describes how hydrogen should be a part of the energy mix, not the sole solution. The second imaginary emphasizes the economic opportunity that GHES can have with an emphasis on cooperation between parties. The third imaginary shows that there are respondents who feel concerned for climate change, but don't see hydrogen as a solution at all. The fourth imaginary sees government intervention as the only way to facilitate this transition. The final imaginary shows that there is a concern for social implications on who will benefit from the transition towards GHES. Practical and theoretical implications are subsequently formulated to better align the technology/energy carrier combination to the normative ideas of stakeholders. According to the respondents, the case looks promising for GHES as there is agreement on GHES becoming a part of the Dutch energy mix. Methods of achieving this goal are e.g., a higher fossil fuel tax, development of technology standards, and the need for international cooperation. Furthermore, conflict items are defined, as is also the goal of Q method, the degree of the focus of economic development, the role of the government to guide and intervene, and the focus on the social implications of the transition towards GHES. These conflict items could be addressed according to an agonistic approach by utilizing social learning and reflexive governance. These practices defined in the literature that have gained eminence and are becoming more accepted. Pertaining to the theoretical implications, sociotechnical imaginaries as a concept fall short of describing the normative future visions as expressed by the respondents. Other scholars have also recognized that the concept might miss diversity in future visions because of its singular interpretation. However, it has been proven possible to, in a quantitative manner (using Q method), describe the sociotechnical imaginaries of around 3/4 of the respondents. The results of this study could be thus for further research be placed in a different social concept such as one of the concepts in the rich umbrella of foresight studies. An example being 'normative scenarios' which recognizes more diversity. Another implication is that it is also possible to use Q-method to peek in the 'black box' of wicked problems. The results show that conflicting visions about the future could be better understood in the context of contestation, uncertainty, and complexity (in other words; wicked problems). Additionally, according to the results, private sector stakeholders are divided on their views of GHES, meaning that shared value creation using open innovation is problematic. An alignment of normative future visions or even a possibility of open innovation without such an alignment is designated as a direction for future research.

1. Introduction

The global climate crisis is one of the most important societal challenges of our time. Climate change is characterized as a so-called wicked problem (Stang & Ujvari, 2015). Problems become wicked when they are uncertain, contested, and complex (Head, 2008). Wicked problems do not have a problem definition or a defined set of solutions (Rittel & Webber, 1973). The global climate crisis requires that the energy industry and its actors and stakeholders (hereafter referred to as stakeholders) go through complex transitions (Bogdanov et al., 2021). One of these transitions is the move away from greenhouse gas (GHG) emitting methods of electricity production. Renewable energy sources such as solar and wind can be harvested to produce electricity without emitting GHGs but are intermittent in nature. Supply and demand often do not run in sync given that the supply of energy sources such as solar and wind cannot be controlled.

Green hydrogen used for energy storage (GHES) can help to solve this intermittency problem. Many scholars and practitioners seriously consider GHES to become part of the future energy mix (Caglayan et al., 2021; Calado & Castro, 2021; Capurso et al., 2022). Implementation of GHES is now rare and limited to particular locations (Widera, 2020). Implementation thus brings new uncertainties with it for private and public GHES facilitators. Uncertainty, contestation, and complexity regarding what kind of technologies will be used and what technologies are desired is an integral part of GHES implementation. Sociotechnical uncertainty, contestation, and complexity regarding the transition to GHES implementation can also hamper focus for research and innovation efforts. Using this lens, the wicked problem literature, for analysis, enriches and clarifies what implications the results of this study can have.

Stakeholders involved (including citizens) have conflicting and coinciding ideas or visions (sociotechnical imaginaries) of what technology should be, as can be compared to science fiction novels, movies, and literature (Jasanoff & Kim, 2015). Sociotechnical imaginaries are defined as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff & Kim, 2015). If the stakeholders involved in GHES are aware of each other's sociotechnical imaginaries, it provides information on the uncertainty, contestation, and complexity discussed previously. Even though many stakeholders believe GHES will and should be part of the future energy mix, it remains unclear what the normative aspects of this technology/energy carrier combination are according to various stakeholders.

This alignment of GHES and the normative ideas of stakeholders benefits the industry and society following Porter and Kramer's notion of shared value (Porter & Kramer, 2019). Shared value creation is centered around "identifying and expanding the connections between societal and economic progress" (Porter & Kramer, 2019). For example, consider a sub-group of respondents that are unified in their view on climate action. For GHES developers, this would be justification for the developments and investments needed for this technology. Perhaps also on a regulatory level in the form of subsidies or favorable entrepreneurial legislation. The opposite scenario is quite likely as well, GHES could turn out to be a dystopian future for another sub-group of respondents of endless investment without desired result. In both scenarios, stakeholders gain knowledge about desired technological future directions.

The research question is thus defined as "What are the different sociotechnical imaginaries of green hydrogen energy storage (GHES) in the Netherlands?" The method through which these sociotechnical imaginaries will be mapped is Q methodology or Q method for short. Q method is chosen because it is suited to describe conflicting and coinciding viewpoints and because the method is built around grouping respondents instead of data, the essence of a "collectively held" (Jasanoff & Kim, 2015) sociotechnical imaginary. As described in the theory section, conflicting and coinciding imaginaries are, amongst other aspects, being sought. Therefore, the aim of this thesis is to identify and describe the sociotechnical imaginaries of GHES of the study respondents so that stakeholders can better align the technology/energy carrier combination with the normative ideas of stakeholders. Note the careful formulation of 'study respondents'. Watts and Stenner (2012) note in their study that generalization of Q methodological results to the whole population requires "great care". Meaning that generalizations must be based on conceptual grounds instead of simply populations of people (Radley & Chamberlain, 2001). The method entails statements (called Q statements) to be placed on multiple Likert scales to obtain groups of respondents with coinciding opinions (Cuppen et al., 2010). Q method is performed according to predefined steps which will be discussed in the methods section. Relevant to the sub-research questions is that defining Q statements is done through building the concourse regarding GHES. The concourse is defined as the collection of possible statements that people make about a subject (Damio, 2016). Sub-research questions are thus defined as [1] What is the wide range of values and concerns that are present in the concourse of GHES technologies? [2] How can the completed Q grids be interpreted to produce sociotechnical imaginaries?

The scientific relevance is twofold. First, insight into the conflicting and coinciding imaginaries on this topic, second, methodological because Q method is relatively new for studying sociotechnical imaginaries. There are few studies where Q method is used to identify and describe sociotechnical imaginaries. A literature search of Web of Science and Scopus yielded five studies published before January 2022 of this kind. This research thesis aims to fill the knowledge gap of on the one hand the construction of imaginaries regarding GHES and on the other the GHES sociotechnical systems in STS. Hess & Sovacool (2020) describe how "the energy studies and STS research field involve distinct and at times disconnected epistemic communities, with different training and approaches populated by different groups of people across space and time." Bridging some of this distinction and disconnect regarding this technology will help in providing guidance for an inherently uncertain, contested, and complex energy transition. Sociotechnical imaginaries as a concept "occupy the blank space between two important literatures, the construction of imaginaries in political and cultural theory and of sociotechnical systems in STS" (Jasanoff & Kim, 2015). The concept itself thus aims to fill a knowledge gap between two literatures. The sociotechnical imaginaries regarding GHES will try to fill this 'blank space' as spoken of by Jasanoff & Kim (2015). The result can be that conflicting visions about the future are better understood in the context of contestation, uncertainty, and complexity (in other words; wicked problems). Furthermore, emphasizing the part where the visions about the future are described, this study departs from the current literature in that it tries to understand the conflict in the present, on desired technological futures. Describing implicit complex imaginaries differs and thus adds to literature where smaller explicit framing is discussed in that it "brings social thickness and complexity back into the appreciation of technological systems" (Jasanoff & Kim, 2015).

The technology perspective of this thesis is on the production and storage of green hydrogen to be subsequently used for energy generation in times of high electricity demand and low electricity supply e.g., winter. The aim of the technology/energy carrier combination is to solve the problems caused by the fluctuating nature of renewable energy production such as sun and wind (D'Errico & Screnci, 2012). The research question and introduction indicate the focus on so-called green hydrogen. However, hydrogen can broadly be produced in three different ways resulting in so-called grey, blue or green hydrogen. Grey hydrogen is produced from natural gas which emits CO2, blue hydrogen is also produced from natural gas but with CO2 capture, and green hydrogen is produced using renewables which emits no CO2. Green hydrogen is the only type produced in a climate-neutral manner (Marchant, 2021). Naturally, the focus of this study is on the only way of producing hydrogen in a climate-neutral manner because it shows the most potential in helping to solve the global climate challenges. Green hydrogen can in its turn be produced in roughly five methods. Thermochemical processes, biological processes, electrolysis, thermolysis, and photo-electrolysis are methods to produce hydrogen without adding GHGs to the atmosphere (Nikolaidis & Poullikkas, 2017).

According to Nikolaidis & Poullikkas (2017), the basic chemical hydrogen storage methods are under high pressure in a gaseous state, as a cryogenic liquid, absorbed on carbon nanotubes, absorbed to form hydrides, and absorbed to form complex hydrides. A hydride is a chemical bond of hydrogen and other elements (Speight, 2020). These chemical or pressurized forms of hydrogen can be stored beneath the surface. The Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland, RVO), has performed research on hydrogen storage in natural sub-surface natural gas networks (Kleinickel & Schulz, 2017).

1.1. Relevance to Management of Technology

For the master Management of Technology (MoT), three general criteria regarding the research thesis are formulated which need to be adhered to. First the work needs to contain an analytical component which is present in both the concourse definition and the analysis of the results. Second the research needs to be multidisciplinary in nature which it also is given that difference social science disciplines are combined, including STS and social energy studies. Finally, the work needs to focus on a technical domain or application which in this case is GHES. MoT is mainly organized around technology, innovation, organization, commercialization, engineering economics, research, and reflection. First and foremost, research and reflection are by design embedded in this research thesis. Furthermore, this thesis relates most to technology and innovation in that the aim of the thesis is to describe the sociotechnical imaginaries of GHES in the Netherlands and to have that knowledge be utilized by the stakeholders to better align the technology to the sociotechnical imaginaries. Essentially, the front-end part of the innovation process for GHES is described in that desired futures for the technology are mapped. Additionally, organization relates to the industry stakeholders who will be aware of desired technology futures and can innovate towards those desired futures. The next section discusses the notions of wicked problems and sociotechnical imaginaries in more detail and tries to further place their relevancy in the context of this research. Furthermore, the technology of analysis is discussed in the next section. Following, the research design and Q method that will be used are described in the research method section. And finally, the discussion is centered around the practical and theoretical implications of the findings. The discussion section is completed with directions for further research.

2. Theory Section

The following chapter will place this research thesis in the context of wicked problems and sociotechnical imaginaries with GHES as the technology for analysis. The concepts are introduced, and knowledge gaps are defined.

The term wicked problem was first coined by Rittel & Weber in 1973. The idea is that wicked problems cannot be clearly defined because of their uncertainty, contestation, and complexity and that they do not have a predefined set of solutions (Rittel & Webber, 1973; Wanzenböck et al., 2020). Wanzenböck et al. (2020) speak of a "problem-solution space" implying complexity and iteration instead of linearity in problem-solving. GHES is potentially considered to be a solution to climate change, a well-known wicked problem (Stang & Ujvari, 2015). Climate change is contested, the outcomes are uncertain, and the nature of the problem and the solutions are extremely complex. Furthermore, wicked problems are defined by contestation because goal formulation by multiple stakeholders is an inherent part of defining the problem (Rittel & Webber, 1973). The notion of explicit goal formulation in planning was introduced in the 1960s and thus, with it, came contestation in goal formulation (Rittel & Webber, 1973). The following quote from the article of Rittel & Weber (1973) describes the then-new notion of goal formulation: "Men in a wide array of fields were prompted to redefine the systems they dealt with in the syntax of verbs rather than nouns – to ask "What do the systems *do*?" rather than "What are they made of?" – and then to ask the most difficult question of all: "What *should* these systems do?" This is relevant because goal formulation is comparable to the formation of sociotechnical imaginaries.

As mentioned in the introduction stakeholders (including citizens) have conflicting and coinciding ideas or visions (sociotechnical imaginaries) of what technology should be, as can best be compared to science fiction novels, movies, and literature (Jasanoff & Kim, 2015). Sociotechnical imaginaries were defined as "collectively imagined forms of social life and social order reflected in the design and fulfillment of nation-specific scientific and/or technological projects" (Jasanoff & Kim, 2009). Jasanoff & Kim later refined the definition to "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff & Kim, 2015). The refined definition, according to the authors, better acknowledges the complexities of sociotechnical imaginaries. Such as how imaginaries form, and the fact that imaginaries do not have to be nation-specific but can be propagated by other organized groups such as corporations or social movements. By mapping sociotechnical imaginaries of GHES, goals are essentially explicitly formulated. The essence of what sociotechnical imaginaries aim to do is connect the disciplines of science and technology studies (STS) and the sociotechnical perspective (Sovacool et al., 2020). According to the article, imaginaries and discourses are the main themes for the future development of sociotechnical perspectives in energy research. The relevancy of sociotechnical imaginaries stems from their capability to narrow this knowledge gap (Sovacool et al., 2020).

According to Head (2008) in the context of wicked problems "we appear to require some new approaches … opening up new insights about productive pathways for better solutions, and thus gaining broad stakeholder acceptance". The distinct definition of problems as wicked means that these kinds of problems acquire special treatment (Alford & Head, 2017). Head (2019) analyses forty years of wicked problem literature and advocates a lower tendency to "quarantine" wicked problems. Utilizing the link between sociotechnical imaginaries and wicked problems provides information on the "sociotechnical dynamics to be better appreciated within … technology planning" (Gjefsen, 2013). Essentially when sociotechnical imaginaries are mapped, it provides information on the wickedness of wicked problems helping to mainstream their analysis. Furthermore, the research by Wanzenböck et al. (2020) provides policy pathways and subsequent implications for these pathways in order to better understand wicked problems. A relevant point to make is that Rittel & Weber (1973) define problems as wicked because of their characteristics and are also thus abstaining wicked problems from becoming 'regular' problems. All the analysis of this research thesis can do is provide information on the wickedness of this problem; it cannot make them less wicked because of the inherent characteristics of wicked problems.

As mentioned before, goal formulation within the concept of wicked problems can be compared to the formation of sociotechnical imaginaries. As with goal formulation, sociotechnical imaginaries are also contested (Jasanoff & Kim, 2015). Sociotechnical imaginaries were understood to be relatively uniform for the nation under analysis when the concept was first introduced (Jasanoff & Kim, 2009). Jasanoff & Kim (2009) mention "multiple contending sociotechnical imaginaries", some more durable than others due to state control but the sociotechnical imaginaries analyzed in this article were presented as uniform in South Korea and uniform in the United States. Jasanoff & Kim (2015) devote an article in the book to contested sociotechnical imaginaries in South Korea and acknowledge that more detailed analysis is needed on a particular South-Korean imaginary. As mentioned in the introduction, Q method is relatively new for mapping sociotechnical imaginaries. However, Q method is well suited for a detailed analysis of any discourse because it correlates respondents who have coinciding opinions. This means that, most likely, groups of respondents are found with conflicting opinions (Damio, 2016).

As mentioned in the introduction, a comprehensive literature search yielded five studies which map sociotechnical imaginaries using Q method. Rodhouse et al. (2021) find that diverse imaginaries can be found using Q method. Gannon et al. (2022) seem to have interpreted the conceptual framing of imaginaries as futures that could instead of should be pursued. This interpretation, which some would argue is flawed, makes learning from this study problematic. Calisto Friant et al. (2021) also identify diverse imaginaries using Q method and enrich their study with a mix of media analysis, policy analysis, and semi-structured interviews. The results is a rich in-depth analysis on the circular economy in the Netherlands. However, the mix of analyses is not used as input for Q method such as concourse development. Cairns et al. (2022) identify three imaginaries but find that an imaginary could be treated as more diverse in itself. An imaginary could consist of multiple elements of each of the imaginaries found in the study. Finally, Wilde & Hermans (2021) find imaginaries on bioclusters (innovate geographical clusters in biotechnology), on in the Netherlands, the other in Germany. What is important to note is that generalizations to the populations are excluded as being impossible, although Watts & Stenner (2012) have argued otherwise.

3. Research Design & Method

This chapter describes how the research was conducted and how it was designed, what research method was used and how.

3.1. Research Design

The research aim is to map sociotechnical imaginaries for the application of GHES in the Netherlands. Sociotechnical imaginaries are a qualitative concept that is thus best described by a qualitative method. Q method adds a quantitative component to the research. It was used for finding the different attitudes of the respondents because according to Stephenson, (1935) it “encompasses a broader philosophy of how subjectivity can best be studied.” Q method thus systematically measured respondents’ viewpoints and was originally developed in the 1930s (Stephenson, 1935). Q method will be explained in further detail below.

The use of Q method for sociotechnical imaginaries in combination with this technology is novel, original data will thus be collected. Q method uses a descriptive research design because it correlates respondents instead of data. For the selection of the population, the quadruple helix model is used, incorporating respondents from four distinct groups, namely private, public, academia, and citizens. The aim is to obtain a respondent group from these four groups of stakeholders to truly speak of sociotechnical imaginaries that represent multiple actor/stakeholder groups. To succumb to the potential obstacles encountered by the respondents, special attention will be given to the ‘condition of instructions’ (see research method section below).

The geographical focus of this study is on the Netherlands and the move towards methods of electricity production which do not emit GHGs. The production method for green hydrogen most spoken of for future development in the Netherlands is electrolysis (Gigler et al., 2021; Kleinickel & Schulz, 2017). The focus of this study will thus be on this production method. The focus of the storage method will be on underground storage as this is already being used in the Netherlands for storing natural gas (Gigler et al., 2021). This method is chosen because it provides the opportunity to store large quantities of hydrogen (Peters, n.d.).

3.2. Research Method

As mentioned in the introduction, a Q method correlates respondents instead of tests, creating groups (Stephenson, 1935). This means that it is possible to find groups of respondents who have coinciding perspectives among themselves and different perspectives between the groups. The aim of the study is to find sociotechnical imaginaries, which are inherent “collectively held” (Jasanoff & Kim, 2015). Sociotechnical imaginaries can also “coexist within a society in tension or in a productive dialectical relationship” (Jasanoff & Kim, 2015). Q method is designed to group respondents and distinguish these groups at the same time.

Q method can according to Yang & Miller (2008) best be described as a method that identifies the operant subjectivity of individuals. It is a tool in which the respondents place predetermined statements, named Q statements, on what is effectively a collection of Likert scales with a varying range. Hence, the method has both a qualitative and a quantitative component. It uses the qualitative judgment of the researcher in defining the problem, formulating Q statements, and selecting respondents while on the other hand, the method of analysis is quantitative in nature. The predefined steps of how to conduct Q method are shown below in Figure 1:

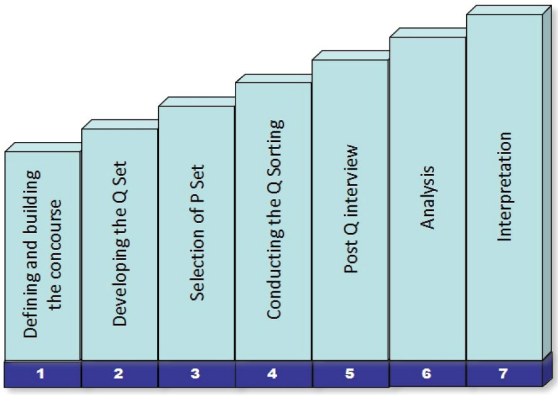

Figure 1 – The stages of Q process (Damio, 2016)

Damio (2016) clearly describes the steps that need to be taken to perform a Q method. What was missing were guidelines and practical steps for performing qualitative research for defining the concourse. Thematic analysis is a method of performing qualitative research that is suitable for new researchers. Furthermore, it is used in several energy-related research articles for concourse definition (Kougias et al., 2020; Damgaard et al., 2022; Matthew et al., 2015). Thematic analysis is considered to be a foundational method for qualitative analysis as it provides core skills for this type of analysis (Braun & Clarke, 2006). Braun & Clarke (2006) also argue that it provides core skills that are relevant for novel qualitative researchers, hence the choice for this type of analysis. Additionally, thematic analysis will be executed according to the 6 phases described by Nowel et al. and the principles as described in their paper. The main thread through the six phases is reflexivity and documentation of actions taken. Nowel et al. (2017) describe a so-called audit trail where the researcher describes the decisions made during the research. This is relevant as the researcher becomes the instrument. The audit trail was kept and incorporated into the report. For all 6 phases of thematic analysis, see Nowel et al. (2017). The following steps guideline is a brief summary of the steps as defined in the article by Damio (2016). For all steps c.f. Damio (2016). The first step is an extension specifically amended for this research according to thematic analysis.

Step 1: Defining and building the concourse

The concourse is defined as the possible statements that people can make about GHES. 'People' is meant according to the quadruple helix model, not to be confused with only the sampled respondents. Damio (2016) references two types of concourses – naturalistic and ready-made. A naturalistic concourse is one taken directly from the respondents through e.g., questionnaires or interviews, a ready-made concourse is taken from sources such as articles. Given the scope of a master thesis, a ready-made concourse will be defined using articles and reviews on GHES. The use of literature reviews will enable the researcher to analyze literature more effectively for statements made on GHES. The articles and reviews will systematically be searched on Web of Science, the biggest and most comprehensive database for scientific literature. The articles will then analyzed for statements. Normative statements made about hydrogen concerning the future are the main criteria for selection for this stage given that the respondents will have to give their opinion on statements during the Q sorting. At this stage, all statements selected by the researcher through the use of thematic analysis as defined by Nowel et al. (2017) will be documented.

Step 2: Developing the Q set

The Q set is the collection of Q statements defined according to and drawn from the concourse. The selection of the Q set is of great importance because it can influence the results. Citing a quote from the article by Damio it remains "more an art than science". Although, citing the following quote from the article by Damio: "the art of good research is to make all methodological judgments transparent and to have a convincing explanation for the choices you make". According to Nowel et al (2017), the statements found in the previous step are then grouped in categories defined by the researcher. The seven categories are: social, technical, economic, political/economic, political, and safety. According to Damio, typically the Q set will consist of 40 to 80 statements.

Step 3: Selection of P set

The following step consists of the sampling of the respondents (also named Q respondents) named the P set. The respondents are selected according to the quadruple helix model as mentioned earlier. This means respondents from the private and public sector, academia, and citizens. Purposive sampling is thus used because respondents need to fall in these categories and/or a view regarding the subject. Furthermore, according to Cuppen et al., (2010), if there is reason to believe someone has a different viewpoint, it is enough reason to include the respondent in the sample. According to research by Damio, a P set typically needs to be no larger than one to three dozen respondents.

Step 4: Conducting the Q sorting

This step involves respondents ranking the statements defined in the previous steps according to their opinion. The conditions of instructions as defined in step 2 are presented to the respondent first. The conditions of instructions have been added to appendix 6. The respondent then starts the sorting by ranking all the statements into three piles of 'relatively agree', 'neutral', and 'relatively disagree'. Subsequently, each pile is taken separately, the statements are reread and placed on the Q grid as shown below in Figure 2 to refine how the respondent feels about that statement. As can be seen below, the three piles made earlier correspond to the three sections on the grid. It is not mandatory to place a statement that is presorted in e.g., 'Neutral' pile on the 'Neutral' section of the grid. The completed Q grids are the input for the analysis step 6.

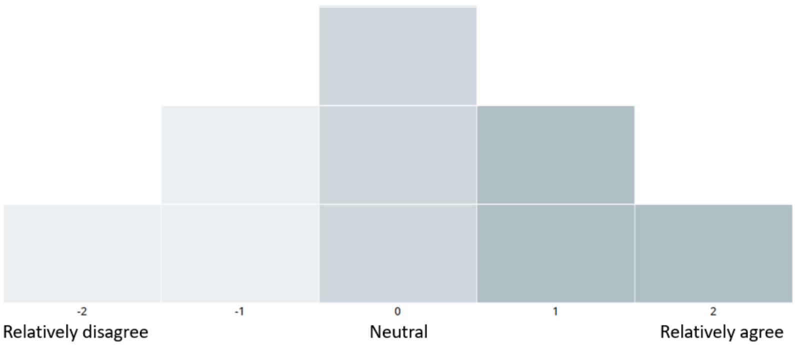

Figure 2 – A example Q grid from the software used

Step 5: Post Q interview

Damio mentions an interview with the respondents after the sorting was complete. The point of the interview according to Damio is to have the respondents "explain the reasons behind the placements of the cards on the grid". Furthermore, Damio mentions an example of recording the positive experience of a respondent in performing the Q sorting. Given the limited time available to perform a master thesis, this step will not be performed. This step is time-consuming, so this step is left out. As a substitution respondents could be contacted via email if any questions arise for the researcher during analysis.

Step 6: Analysis

The Q grids are going to be analyzed using factor analysis, as by design according to Q method, creating different groups of opinions. In short, factor analysis is a technique to search for correlations and explained variance and covariance between the respondents. This generates multiple groups (called factors) of respondents. Data reduction is the essence of factor analysis, creating the possibility for meaningful qualitative analysis (Watts & Stenner, 2012). In line with this study, it is then possible to qualitatively derive sociotechnical imaginaries from the composite Q grids that are associated with a factor.

Qualitatively, a factor is an unobserved variable of multiple of the observed variables in the statements placed on the Q grid. Quantitively, a factor thus explains most of the (that is the objective) variance and covariance of the observed variables in the statements placed on the Q grid. An example of this is an observed variable in the statements like a positive attitude towards hydrogen, which can be explained by an unobserved variable (in this study) i.e., the sociotechnical imaginary. This imaginary could for example revolve around a concern for future generations which is unobserved (not explicitly mentioned) in the statements. This last part is interpretation and is performed in step 7 described below.

In more detail, factor analysis consists roughly of two steps. Factor extraction and subsequently factor rotation. For factor extraction, QMS has two methods, namely Principal Component Analysis (PCA) and Centroid Factor Analysis (CFA). PCA provides a "single, mathematically best solution, which is the one that should be accepted" (Watts & Stenner, 2012). CFA will be used given that PCA thus "deprives us of the opportunity to properly explore the data or to engage with the process of factor rotation in any sort of abductive, theoretically informed or investigatory fashion" (Watts & Stenner, 2012). The goal is to find factors where at least two or more respondents significantly load on each of the factors in combination with factors that are interpretable. If only one respondent loads significantly on a factor, this factor is essentially the Q sort of that respondent, defying the goal of the data reduction technique that is factor analysis. The Kaiser-Guttman criterion and Humphrey's rule can be used to determine which factors will be extracted for rotation. The Kaiser-Gutmann Criterion states that when factors have an Eigenvalue greater than 1, they should be extracted for rotation and subsequent analysis. However, Yeomans & Golder (1982) state, as advice, not to "place too much reliance on the results of applying the Guttman-Kaiser criterion". Humphrey's rule states that when the cross-product of the two highest loadings exceeds twice the standard error, it should be extracted for rotation and subsequent analysis. Again, not suited for solely determining how many factors should be extracted. The point made here is to also look at the number of respondents significantly loading on each factor and qualitatively assess if the factors are interpretable. This is only possible after factor rotation, so the point is to take an iterative approach to find interpretable factors.

The second step is factor rotation. There are several prevailing methods such as Varimax and Hand Rotation. Hand Rotation requires e.g., detailed interview data, which is not incorporated in this study. The reason for this is made clear in step 5. Detailed interview data would provide information on the perspectives of respondents. For example, a perspective is made clear through an interview and this respondent might be the 'poster child' for this specific perspective. It then makes sense to use Hand Rotation to make that respondent load more significantly on this perspective. Varimax rotation is thus better suited and is most commonly used in Q method and will therefore be applied (Akhtar-Danesh, 2017). Furthermore, Varimax rotation reveals (through maximizing explained variance) the viewpoints that are favored by the respondents (Watts & Stenner, 2005).

Several indicators will together be used to determine how many factors will be extracted, rotated, and interpreted as imaginaries. First, the Kaiser-Guttman criterion and Humphrey's rule will be used, together with a cumulative variance explained that needs to be at least 40%. As mentioned earlier, at least two respondents need to load significantly on each factor. Finally, the total number of respondents that significantly load on all factors combined needs to be between 66% (N=27) and 75% (N=31). All these quantitative indicators can help in determining the number of factors for extraction and rotation, but qualitative assessment is the decider.

Step 7: Interpretation

Interpretation of the factors is when appropriate descriptions are added to the multiple groups of respondents found. An example would be to name the factor of respondents with coinciding positive opinions towards hydrogen as 'Start transitioning rather sooner than later'. This kind of interpretation will be done by looking at the correlation coefficients of the factors together with a qualitative interpretation of the placement of statements on the composite Q grid. This will be done by using so-called crib sheets. Crib sheets will be further described below in Chapter 4.3.

The final step is not defined in the article by Damio in that it requires the interpretation of the factors in relation to the wicked problem and sociotechnical imaginaries concepts. What do the factors mean? What are the implications? What are directions for further research?

For performing Q method, ‘Q Method Software’ (QMS) was used. This software (website) was perceived as user-friendly by the researcher and gives the researcher the opportunity to perform the analysis without using a separate statistical program. A list of respondents can be stored on the website and all text shown to the respondents can be modified to make sure that correct information such as the instructions is provided. There are multiple factors and rotating analysis methods built into the software, the different methods and the methods used are discussed below in step 6.

4. Results

This chapter will discuss the concourse development and the factor analysis of the 41 Q sorts handed in by as many respondents from the industry (10), the public sector (10), academia (8) and from respondents in their role as citizens (13), following the quadruple helix model.

4.1. Concourse Development

As mentioned in the method section, defining the concourse requires scanning articles on statements made about GHES. An overview of the search terms used are:

TOPIC: "green hydrogen" AND storage AND imaginaries (0 articles)

TOPIC: "green hydrogen" AND storage AND foresight (0 articles)

TOPIC: "green hydrogen" AND storage AND future (75 articles)

Any other combination of searching for the technology such as [“green hydrogen storage”] or [hydrogen AND storage] or [green AND hydrogen AND storage], or [green AND “hydrogen storage”] either yields no, more than 800, or more than 2000 publications. Striking to see is that no articles were found when combining the search with imaginaries. This indicates the novelty of describing the imaginaries for this technology. Using the term “foresight” gave no results but when searching for “future”, 75 publications were found including 19 review articles. The title of the articles was the first filter for selection, the abstract was the second. In total 10 articles including 3 review articles are found. Below in Figure 3, a flow diagram is shown of the search process:

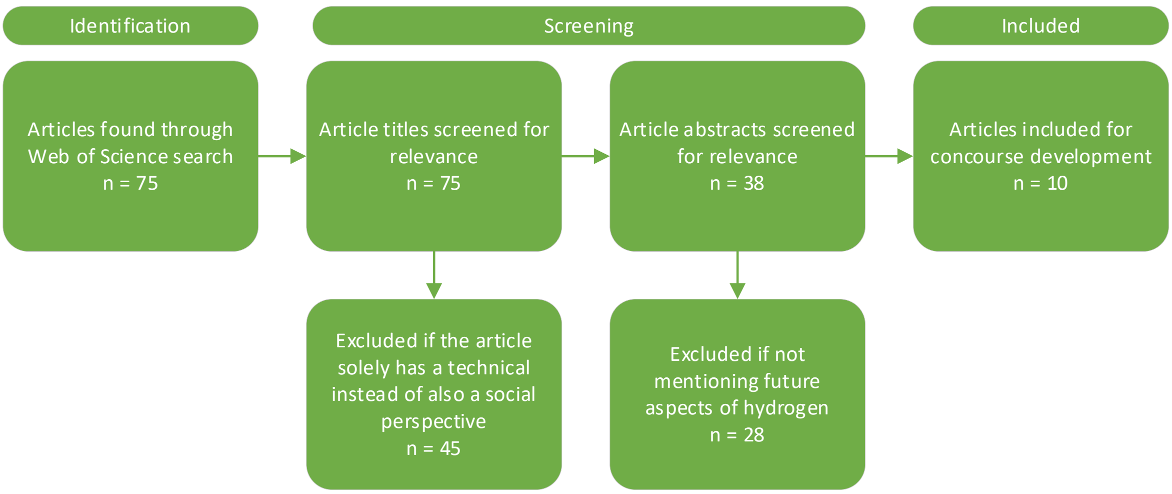

Figure 3 – Flow diagram of the selection process (based on Doorn, 2021)

Below in Table 1, an overview of the information on the articles used for concourse development.

Table 1 – Overview of the articles used for concourse development

Author(s)	**Year**	**Title**	**Keywords**
Dilara Gulcin Caglayan, Heidi U. Heinrichs, Martin Robinius, and Detlef Stolten	2021	Robust Design of a Future 100% Renewable European Energy Supply System with Hydrogen Infrastructure	Renewable energy systems; Energy supply systems; Hydrogen pipelines; Power-to-hydrogen
Gonçalo Calado and Rui Castro	2021	Hydrogen Production from Offshore Wind Parks: Current Situation and Future Perspectives	Green hydrogen; offshore wind; Techno-economic analysis; Water electrolysis;

			Grid integration
T. Capurso, M. Stefanizzi, M. Torresi, and S.M. Camporeale	2021	Perspective of the Role of Hydrogen in the 21st Century Energy Transition	Hydrogen; Power to Gas; Decarbonization; Energy transition; Renewable energy; Sustainability
Roberto Fazioli and Francesca Pantaleone	2021	Macroeconomic Factors Influencing Public Policy Strategies for Blue and Green Hydrogen	Blue hydrogen; Green hydrogen; Carbon capture; Sustainability; Energy transition
Nicholas Gurieff, Behdad Moghtaderi, Rahman Daiyan, and Rose Amal	2021	Gas Transition: Renewable Hydrogen's Future in Eastern Australia's Energy Networks	Renewable hydrogen; Electricity network; Gas network; Power-to-gas; Gas-to-power; Energy transitions; Green hydrogen; Energy networks; Energy storage; Electrolysis
Renata Koneczna and Justyna Cader	2021	Hydrogen in the Strategies of the European Union Member States	-
Alexandra M Oliveira, Rebecca R Beswick, and Yushan Yan	2021	A Green Hydrogen Economy for a Renewable Energy Society	-
Cesare Saccani, Marco Pellegrini, and Alessandro Guzzini	2020	Analysis of the Existing Barriers for the Market Development of Power to Hydrogen (P2H) in Italy	Hydrogen; Power to hydrogen; Smart grid; Electrolysis; Hydrogen grid; Green hydrogen
Manfred Wanner	2021	Transformation of Electrical Energy into Hydrogen and its Storage	-
Bas van Zuijlen, William Zappa, Wim Turkenburg, Gerard van der Schrier, and Machteld van den Broek	2019	Cost-optimal Reliable Power Generation in a Deep Decarbonization Future	Power system modelling; Carbon neutral power systems; CCS; Intermittent renewable energy sources; Negative emissions;

The seven categories as defined in the method section, step 2 are: social, technical, economic, political/economic, political, and safety and are used to select the statements which will be left out of the Q set. The Q set was thus formed by deleting the statements that are not relevant instead of selecting the statements that are relevant. The number of statements per category was used as a guide to find several statements proportionate to that category, although it was not a requirement. The statements were selected based on their merits. All statements (n = 103) where documented at this stage.

Reflexivity was then incorporated in the formation of the statements by discussing them with both thesis counselors who have used Q method before and a PhD candidate who is writing her dissertation partly on hydrogen in the Netherlands and who has also used Q method before. Striking to see was that the thesis counselors gave separate corresponding feedback on the statements. A suggestion to provide a more balanced set was to sort the statements according to how a hydrogen enthusiast, techno-optimist, and pro-government respondent would sort the statements. This also gave insight into how a hydrogen-pessimist, techno-pessimist, and government-critical respondent would sort the statements. The conclusion of this exercise was that the set was skewed in favor of the hydrogen enthusiast, techno-optimist, and pro-government respondent. Rephrasing the statements to find a more balanced set solved this problem. Finally, the set consisted of a total of 35 statements. Given the limited scope of this master thesis, the lower bound was adhered to with a small margin.

4.2. Factor Extraction and Rotation

Factor extraction and rotation followed after the 41 respondents completed the sorting of the statements. The correlation matrix (41 x 41) has an average of 0,336, meaning that the respondent's perspectives are heterogeneous. The next step is Centroid Factor analysis as discussed in the method section. According to both the Kaiser-Guttman criterion and Humphrey's rule, 6 of the 7 factors are to be extracted for factor rotation. Values for both methods of selection for factor extraction are shown below in Table 2. The table below, together with the number of respondents who significantly load on each factor and a qualitative interpretation, is used for determining the number of factors extracted. The qualitative interpretation is done using the sort value table in Appendix 3. Do the factors tell a different story? Does keeping a factor provide meaningful results?

Table 2 - Initial factor information

Values	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
Eigenvalue	15,46437	2,52765	2,03568	1,56461	1,21697	1,44026	0,93323
% Explained variance	37,71798	6,16501	4,96508	3,81613	2,96822	3,51283	2,27618
Cumulative variance	37,71798	43,88298	48,84806	52,66419	55,63241	59,14525	61,42143
Humphrey's rule	0,77355	0,31768	0,24932	0,21534	0,13734	0,12214	0,09823
Standard error	0,05	0,05	0,05	0,05	0,05	0,05	0,05

Determining the number of respondents who load significantly on each factor requires performing the next step of factor analysis which is factor rotation using Varimax. According to the Kaiser-Guttman criterion and Humphrey's rule, 6 factors are to be extracted for factor rotation, shown below in Table 3. Table 4 shows the number of respondents loading significantly on each factor when the number of factors extracted and rotated is reduced to 5.

Table 3 - Respondent loading with 6 factors extracted

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
No. of defining variables	5	8	2	5	2	1

Table 4 - Respondent loading with 5 factors extracted

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
No. of defining variables	7	7	4	7	2

The above tables show that when five factors are extracted and rotated, the criteria as defined in the method section of a minimum of two respondents loading significantly on each factor is satisfied. This means that in total, 27 out of 41 respondents significantly load on the factors, i.e., the lower bound of 66%. As identified in the research method section the range is between 66% (N=27) and 75% (N=31). The conclusion is that five factors will be kept for interpretation, given that meaningful unique interpretations are also possible as seen in the sort values table in Appendix 3 on all factors. By extracting five factors, the total variance explained is 55,63%. Meaning that this also meets the criteria of a minimum of 40%.

4.3. Factor Interpretation

The five factors are interpreted to determine what sociotechnical imaginary they represent. The rotated factors are perceived as different perspectives (different sociotechnical imaginaries) relative to each other on GHES. What should be understood is that Q methodological results should be generalized to the whole population with "great care" (Watts & Stenner, 2012). In other words, the results can be interpreted as an indication of the sociotechnical imaginaries of the population but should not be assumed to be so. Generalizations must be based on conceptual grounds instead of simply populations of people (Radley & Chamberlain, 2001). Qualitative interpretation of the factors is done by using a crib sheet for each factor. A crib sheet is a list of statements that shows the sorting positions of the statements relative to each other in a orderly manner to make interpretation easier. Crib sheets are produced by QMS and contain distinguishing statements, consensus statements, and characteristic and uncharacteristic statements for each factor. These crib sheets are added to the appendix. Statement numbers are placed in parenthesis (), and statement sorting values are placed in square brackets [].

Sampling was performed according to the quadruple helix model. Analyzing the relationship of the factor with that the role of the respondents loading on that factor (private, public, academic, or citizen) could provide insight. Below in Table 5 is an overview of the number of respondents per professional role loading on each factor.

Table 5 - Division of loading and not loading respondents per professional role

	Academic	**Citizen**	**Private**	**Public**
Loading	5	9	7	6
Not loading	3	4	3	4

A deeper look at similarities and differences based on the correlation coefficients of the factors *relative* to each other is discussed below. Important to note is that the factor interpretations below should only be read as being *relative* to each other. This is because a statement placed on [0] cannot be interpreted as a respondent being indifferent to that statement. For reading convenience, this is not repeated every time an interpretation of an expressed future vision is presented below. Furthermore, two spectra are identified from the concourse. Respondents (relative to each other) are placed for illustrative purposes in categories of hydrogen-optimist vs hydrogen-pessimist and pro-government vs government-critical.

What is striking to see is that statement (3); "Climate change concerns me", is placed on Q tile [+5] for 3 of the factors. What this indicates is that the statement carries weight for most respondents. Q methodology requires holism, meaning that it requires looking at the entire dataset (Watts & Stenner, 2012). With this in mind, statement (3) is used more heavily for interpretation than other statements, given its striking sorting position by respondents. For reading convenience, the distinguishing statements are added to each factor, the rest of the crib sheet was also used for interpretation.

Factor 1 – "We are hydrogen-optimistic and critically realistic"

Seven respondents have a unique significant loading on factor 1. Four respondents from the private sector, one respondent from the public sector, one citizen, and one academic.

Table 6 - Distinguishing statements for factor 1

No	**Statement**	**Category**	**Sort values**
12	Green hydrogen is but one of the many renewable energy solutions that we need to accomplish our climate change mitigation goals.	Technical	4
4	Public ownership of large-scale hydrogen storage is not necessary for future market acceptance of green hydrogen.	Social	-1
6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	Technical	-2
11	Hydrogen will be especially important in the energy sector.	Technical	-5

As can be seen, climate change is a concern for this group, but GHES is not seen as the holy grail solution. Statement (10) states that a sustainable future can be obtained without GHES, and this factor disagrees with this statement the most out of the 5 factors. One statement (12) says that there will also be other methods of energy storage and is highly ranked. Another statement (11) says that hydrogen will especially be important in the energy sector and is ranked lowest. In total three statements (6, 11, 12) are placed in such a way that it expresses mild enthusiasm, combined with a realistic future view. What is interesting to see is that the statement of the Netherlands becoming a major import and trade hub is ranked highest. This is thus seen as a benefit. The professional roles of the respondents loading on this factor cannot directly be explained by being mildly enthusiastic about GHES.

Factor 2 – "Hydrogen: a driver for economic opportunity"

Seven respondents have a unique significant loading on factor 2, as is the case with factor 1. Five citizens, one respondent from the private sector, and one academic.

Table 7 - Distinguishing statements for factor 2

No	Statement	Category	Sort values
18	Based on its current leadership position in gray hydrogen production, the Netherlands should aim to become one of the biggest green hydrogen producers in Europe.	Economic	3
23	The government should intervene as little as possible in the currently developing hydrogen market.	Political	2
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	1
34	There will be better - cheaper, and easier - methods of energy storage than green hydrogen.	Technical	-2
19	Cost efficiency of hydrogen technologies can only be marginally improved via innovation.	Economic	-5

Without over-characterizing, this is one of the two factors without "Climate change concerns me" placed on +5. The sort value for this statement is [0]. Counter to this, what is striking about this factor is the emphasis on the leadership and pioneering position of both the EU and the Netherlands when it comes to GHES. Additionally, dynamic and open regulations, as little government interventions as possible, and tax breaks or stimuli are favored. Meaning that this group is positive towards a conducive government rather than a visionary government leading the way. This can be seen in statement (29) which is placed on [0], stating "clear policies and regulations". This factor, as does factor 4, also recognizes the need for standardization for GHES technologies development. Additionally, the agreement on international cooperation, as well as cooperation within the EU is striking. This should not be confused with deep governmental cooperation as this group is not outspokenly supportive of public ownership of GHES facilities. Overall, this imaginary can thus be characterized as hydrogen-optimistic with the perspective of the benefit of technical and economic development for the Netherlands and the EU, made possible through cooperation. The professional roles of the respondents are not easily explained. These citizens could value economic development more strongly than the other professional roles or these seven respondents could be more on the government-critical side of the political spectrum.

Factor 3 – "We're not excited"

Four respondents have a unique significant loading on factor 3. Two academics, one respondent from the public sector and one from the private sector.

Table 8 - Distinguishing statements for factor 3

No	Statement	Category	Sort values
10	A sustainable future can be accomplished without hydrogen technologies for energy conversion and storage.	Technical	4
33	Innovations in electrical storage could make green hydrogen redundant.	Technical	2
16	Green hydrogen storage technologies should only be developed if there is an economically viable business case.	Economic	1
27	Europe must become the world leader in electrolyzer technology.	Political	-1
22	We should turn the Netherlands into a pioneering country when it comes to hydrogen energy storage technologies.	Political/economic	-3
7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	Technical	-3
28	International cooperation is not needed for the development of green hydrogen energy storage technologies.	Political	-4
6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	Technical	-5

High concern for climate change, but hydrogen is not the solution. The disliking towards hydrogen is apparent when looking at the category most uncharacteristic where four out of six statements are placed which shows that a negative opinion on GHES exists within this group of respondents. Again, this point is made when looking at the distinguishing statement which is ranked highest stating that "innovations in electrical storage could make green hydrogen redundant" [+2]. Furthermore, statement (6) saying that hydrogen can facilitate a full reduction in the energy sector is placed lowest of the five factors. Important to note is the high favorability of government intervention in any form, signaling pro-government tendencies. This group is extremely hydrogen-pessimistic, which is striking given the high concern for climate change. The professional role of the respondents is interesting, it is the only factor with two academics significantly loading. These two academics might be better informed on the downsides of GHES.

Factor 4 – "Welcome state intervention"

Again, seven respondents have a unique significant loading on factor 4. Four respondents are from the public sector, two citizens and, one respondent from the private sector.

Table 9 - Distinguishing statements for factor 4

No	Statement	Category	Sort values
17	Because of the speed of climate change, we do not have the luxury of waiting for hydrogen technologies to become cost competitive.	Economic	4
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	0
7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	Technical	0

And again, high concern for climate change and subsequent action needs to be taken. This factor shows the highest pro-government tendencies of all factors. Some skepticism when stating that hydrogen is not the sole solution [+3]. The distinguishing statement 7 and 8 are placed on [0], meaning indifference to statements saying that hydrogen should play a critical role or be the primary means of renewable energy storage. The government is welcome to intervene and guide, as can be seen from the placement [-5] of the statement "the government should intervene as little as possible in the currently developing hydrogen market". Furthermore, the most characteristic statements show a high tendency for government intervention in the roll-out of GHES. Not only the government needs to act, but cost competitiveness also needs to be achieved. From a technical perspective, the benefit of technology standards is recognized (just as in factor 2). The professional roles of these respondents are to be expected given that public sector respondents would most likely advocate for more governmental intervention.

Factor 5 – "Hydrogen storage is the way to go, but be aware of big industry"

Two respondents have a unique significant loading on factor 5. One academic and one citizen.

Table 10 - Distinguishing statements for factor 5

No	Statement	Category	Sort values
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	5
5	Social acceptance is one of the most critical barriers for success of hydrogen storage.	Social	4
15	Domestic green hydrogen production will have a marginal effect on the Dutch economy.	Economic	2
11	Hydrogen will be especially important in the energy sector.	Technical	-1
29	We need more clear policies and regulations on the possibilities of hydrogen conversion and system integration.	Political	-2
35	The Netherlands should become a major hydrogen import and trade hub because of its many strategic advantages, such as its existing infrastructure and underground hydrogen storage potential.	Economic	-3
34	There will be better - cheaper, and easier - methods of energy storage than green hydrogen.	Technical	-5

This factor represents a view favoring hydrogen storage, but with concern for the social implications. For example, this statement that incumbent energy companies will benefit most from the move toward hydrogen is placed highest [+2] of the 5 factors. Moreover, the statement saying that public ownership of large-scale hydrogen facilities is needed for market acceptance (4), shows a reluctant attitude towards bigger industrial players. Together with the antipathy towards being a major hydrogen import and trade hub [-3] (ranked lowest of the 5 factors) and the Netherlands becoming the biggest EU green hydrogen producer, the cautiousness towards big industry is apparent. This can be linked to the fear of a lack of social acceptance for hydrogen storage technologies which this group strongly agrees with because it is placed on [+4]. Respondents from this group are positive on hydrogen for energy storage but mostly negative on other uses of hydrogen such as large-scale production (18) or in relation to the Netherlands becoming an import and trade hub (35). In conclusion, the respondents in this factor seem to feel that hydrogen purely for energy storage is a good idea but are hesitant about the societal benefits and impact. Will it benefit society? What happens when bigger industry players take over and reap the benefits? The professional role of the respondents is marginally relevant here given that there is no outlier among the categories academic, private, public or academic. The loading respondents being one academic and one citizen respondent cannot explain the tendency for concern for social implications.

Comparing similarities and differences

Similarity is seen in statement (3) "Climate change concerns me" which is placed on [+5] for 3 of the 5 factors. Statement (21) [around +3] and (25) [around 0] are consensus statements for all factors. What this means for statement (21) is interpreted as respondents agreeing that fiscal measures would trigger renewable behavior. The placing of statements (25) is interpreted as either respondent not being aware of what these recent EU ambitions are or that respondents are simply indifferent.

To compare the factors, the correlation matrix as can be seen below in Table 11 is used. The average of all coefficients below is 0,31, indicating that there is a moderate dissensus between the 5 factors overall. In other words, the 5 factors represent distinctly different perspectives. What is apparent is that all but one coefficient is positive. Indicating that there is consensus on an aspect described in the statements. This consensus is, as can be seen below in the qualitative interpretation, is interpreted as the (moderate) optimistic attitude towards hydrogen of all factors but factor 3. Furthermore, Table 12 shows the average coefficients per factor which indicates homogeneity of factors 1 and 4 relative to the other factors.

Table 11 - Factor correlation matrix

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
Factor 1		0,33	0,32	0,59	0,43
Factor 2			0,04	0,49	0,29
Factor 3				0,29	-0,10
Factor 4					0,41
Factor 5					

Table 12 - Average correlation

	Average
Factor 1	0,42
Factor 2	0,29
Factor 3	0,32
Factor 4	0,44
Factor 5	0,26

On the basis of the data shown in the crib sheets and the correlation matrices above, a more detailed comparison can be made. The bi-factor comparison below is based on the correlation coefficient, meaning that outliers (high or low correlations) are a reason for a more in-depth look. The goal is to create insight into the differences and similarities of each factor relative to the other factors. For convenience, the respondents loading significantly on each factor are described as the factors themselves.

Bi-factor comparison

Factors 1 and 2 correlate moderately (0,33). Factor 2 places the emphasis on the Dutch and European leadership position regarding hydrogen whereas factor 1 agrees more with statements on moderating the enthusiasm for hydrogen but at the same time expresses concern for climate change.

Factors 1 and 3 correlate moderately (0,32). A clear similarity is a high concern for climate change (+5). A more subtle difference is the skepticism towards hydrogen. Factor 1 is moderately skeptical or healthy skeptic whereas factor 3 denies hydrogen to be a part of the solution at all. Furthermore, factor 1 shows only modest enthusiasm for government intervention whereas factor 3 is strongly positive towards government intervention.

Factors 1 and 4 correlate strongly (0,59). This strong correlation is based on two aspects, factors 1 and 4 show realistic enthusiasm towards hydrogen. And second, these two factors agree on a mild leadership position of the Netherlands and the EU, shown in positive statements about this subject (22, 27, 35). What can be seen more distinctly in factor 4 is the positive attitude towards government intervention. This is where factor 4 differs given the tendency of respondents loading on factor 1 to have a mildly negative opinion of government intervention. Factor 4 differs in the value placed on the consideration for the potential negative effects of GHES: factor 1 [-2] and factor 4 [+2]. What this indicates is the difference in the sense of urgency when it comes to the speed of implementation.

Factors 1 and 5 correlate moderately (0,43). Factor 5 is more enthusiastic about hydrogen storage, but with concerns about who will benefit from and who will execute the transition towards hydrogen. Factor 5 agrees most of all factors with statement 20, saying that incumbent energy companies will benefit most. Together with factor 5 agreeing most of all factors on statement (5) saying that social acceptance is the greatest barrier, factor 5 differs from factor 1 and the others in that there is a concern for social aspects.

Factors 2 and 3 don’t correlate (0,04). The obvious difference is the complete opposite opinions on hydrogen. Factor 2 sees hydrogen as an opportunity for economic development whereas factor 3 doesn’t see a future for hydrogen at all. Additionally, factor 3 shows pro-government tendencies, whereas factor 2 is more characterized by economic development.

Factors 2 and 4 correlate moderately to strongly (0,49). What these factors agree on is the move forward towards hydrogen although the method and implication of the move forward are contested among these two perspectives. Factor 2 mainly sees GHES as an economic opportunity for becoming a leader as can be seen from statements (22) [+5], (27) [+3], and (35) [+2]. Whereas factor 4 is more positive on the role of government intervention, as can be seen in statement (23): factor 2 [+2] and factor 4 [-3]. Factors 2 and 4 both recognize the need for technology standards for the development of GHES (1). Furthermore, when looking from a technological perspective, innovations in electrical storage are for both factors not considered as making GHES redundant.

Factors 2 and 5 correlate weakly (0,29). A weak correlation is to be expected given the nature of the factors. Whereas factor 2 is more positive on economic development, factor 5 is careful about the socio-economic implications of a move toward GHES. Hydrogen is thus for both factors the way to go, although the motivations for doing so differ.

Factors 3 and 4 correlate weakly (0,29). Although there is agreement on state intervention, the difference is in the enthusiasm toward hydrogen. Both factors do agree on similar statements but disagree on different statements. The difference is interpreted as factor 3 being hydrogen-pessimistic factor 4 is hydrogen-optimistic.

Factors 3 and 5 correlate negatively weakly (-0,10). It fits in the overall tendency of factor 3 to correlate weakly (or in this case negative) with the other factors. Factor 3 is negative on extremely negative on hydrogen, explaining the difference with factor 5, which is highly optimistic.

Factors 4 and 5 correlate moderately (0,41). What explains the slightly higher correlation is the positive attitude towards government intervention. The difference can for a small part be explained by the concern for climate change: factor 4 [+5] and factor 5 [+1]. The concern seems to focus more on big industry in factor 5 than on climate change.

Multi-factor comparison

Statistically comparing, given Table 12, factors 1 and 4 correlate highest with the other factors meaning that one of the viewpoints expressed in these factors is shared in relation to the other factors. Qualitatively comparing the factors shows that factor 1 is marginally excited about hydrogen, factor 2 is positive, factor 3 is outspokenly negative, factor 4 is also marginally excited and finally, factor 5 is positive as well. In total 4 factors are perceived as hydrogen-optimistic and 1 factor as hydrogen-pessimistic. The one factor that is hydrogen-pessimistic (factor 3) correlates lowest (or negative) with the other factors. Hydrogen optimism is what mostly explains the higher correlation coefficients in relation to the other factors for factors 1 and 4 based on the qualitative interpretation. Furthermore, a contested aspect in the discussion around climate mitigating measures such as GHES is whether or to what extent the government should intervene or help in this transition. Can the respondents be gathered under the denominators pro-government or government-critical relative to each other? Factor 1 is critical of government intervention while factor 2 is against government intervention altogether. Factor 3 exhibits stronger pro-government tendencies while factor 4 is open to government intervention (not meaning pro-government). Finally, factor 5 is indifferent or mildly open to government intervention. These factors are therefore not easily named pro-government or government-critical, which makes sense given that the respondents would most likely fall on a spectrum.

5. Discussion

This section discusses the results, practical and theoretical implications, and any shortcomings or limitations of this master thesis, the research method, and the concepts and the way they are applied. Finally, directions for further research are discussed. This section assumes that GHES will be a part of the Dutch energy mix. The question which then arises is: where to go next and what to abandon according to the actors? The aim of this thesis is to identify and describe the sociotechnical imaginaries of GHES in the Netherlands so that actors can better align the technology/energy carrier combination with the normative ideas of stakeholders. The imaginaries have been named: [1] “We are hydrogen-optimistic and critically realistic”, [2] “Hydrogen: a driver for economic opportunity”, [3] “We’re not excited”, [4] “Welcome state intervention”, and [5] “Hydrogen storage is the way to go but be aware of big industry”. What should be noted is that the following description should be read relative to each other throughout the discussion. E.g., enthusiasm towards hydrogen means relative enthusiasm. The first imaginary mainly describes how hydrogen should be a part of the energy mix, not the sole solution. The second imaginary emphasizes the economic opportunity that GHES can have with a strong emphasis on cooperation between parties. The third imaginary shows that there are respondents who feel concerned about climate change, but don’t see hydrogen as a solution at all. The fourth imaginary sees government intervention as the only way to facilitate this transition. The final imaginary shows that there is a concern for social implications on who will benefit from the transition towards GHES. There are several practical implications to be drawn from these imaginaries. Consensus and conflict items can help to identify where to go next and what to abandon. These consensus and conflict items are identified below.

Consensus items

Statement 3 “Climate change concerns me” is placed on [+5] for three of the five imaginaries, meaning that for this statement there is consensus. The other two imaginaries place this statement on [0] or [1], indicating indifference. Overall, there is also consensus on the statement “Green hydrogen is but one of the many renewable energy solutions that we need to accomplish our climate change mitigation goals”. Building on this, there is consensus on the inability of achieving a sustainable future without hydrogen, except for one imaginary. Moreover, statement (21) saying that a higher fossil fuel tax would incentivize industrial players to adopt hydrogen technologies is placed in agreement for all imaginaries. From a technical perspective, actors agree on the need for technology standards for the development of hydrogen technologies. Additionally, pertaining to the technology, respondents agree that innovations in electrical storage will not make GHES redundant. A final technical consensus point is the perceived safety of hydrogen use in relation to fossil fuels. Furthermore, the role of the EU is not considered to be groundbreaking as respondents are mostly indifferent. This is interesting because most actors agree that international cooperation is needed for the development of GHES. Below the consensus items are summarized:

1. Actors are concerned about climate change.
2. Actors urge that GHES is part of the solution to achieve climate mitigation goals.
3. Actors agree on the inability of achieving a sustainable future without GHES.
4. Actors feel that a higher fossil fuel tax would incentivize industry players to adopt hydrogen technologies.
5. Actors have mostly expressed that technology standards are necessary for development.
6. Actors mostly don’t feel that innovations in electrical storage will make GHES redundant.
7. Actors are strongly in agreement that hydrogen will not be more dangerous in use than fossil fuels.
8. Actors are indifferent to or unaware of, the recent ambitions on hydrogen by the EU.
9. Most actors are also indifferent to the statement saying that the EU should demonstrate more interest in GHES.
10. Actors agree on the need for international cooperation.

Conflict items

When it comes to the economic development potential of GHES, actors are divided. This can among other statements be seen in statement (16) “Green hydrogen storage technologies should only be developed if there is an economically viable business case” which shows little agreement. Actors are also divided on the statement saying that hydrogen should be the primary means of renewable energy storage. This can also be seen when looking at the statement “Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector”. Public sector actors in the fourth imaginary feel that there should be room for the government to guide and intervene in the transition towards GHES. For actors, there is no consensus on keeping the social implications top of mind in this transition. Below the conflict items are summarized:

1. Actors disagree on the economic development potential of GHES.
2. Actors are divided on hydrogen being the primary means of renewable energy storage.
3. Actors are not in agreement on whether hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.
4. A small fraction of the actors feels that there should be room for the role of government to guide and intervene.
5. A small portion of the actors urge that the social implications of the move towards GHES should be considered.

In order to learn from the practical implications, they first need to be placed in the existing theoretical framework of this thesis. Sociotechnical imaginaries are described as “collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology” (Jasanoff & Kim, 2015). These “visions of desirable futures” shape goal formulation as defined in the wicked problem literature (Rittel & Webber, 1973). Aspects of the wicked problem literature are thus used, in combination with sociotechnical imaginaries, to discern normative future directions for the GHES debate. These normative future directions are, as was found in this study, characterized by contestation and disagreement. An agonistic approach as defined by Popa et al. (2021), replaces “discussion stoppers with discussion starters and … standstills with contestation”. It is about recognizing that consensus in the form of a resolution (and/or in the form of ‘agree to disagree’) should not be the end or end goal of conflicting visions or perspectives. This recognition can, according to Popa et al. (2021), be achieved by using the agonistic approach as a ‘technology of humility’. Humility in this sense means recognizing when to “stop turning to science to solve problems” (Jasanoff, 2007). Imaginaries are partly shaped by science as can be seen in the definition of sociotechnical imaginaries by Jasanoff & Kim but, non-science normative future visions should have a place in technological development. Furthermore, Wanzenböck et al. (2020) define three policy pathways in an attempt to identify how policy moves from being ‘wicked’ to a problem-solution constellation. The hybrid policy pathway can be characterized by the climate change (problem) GHES (solution) combination. First, Stang & Ujvari (2015) characterize climate change as a wicked problem. Second, because “Climate change concerns me” is placed in exceptional consensus. Finally, GHES is seen as a solution in some of the imaginaries. However, the problem-led policy strategy is useful because it is defined as a merger of “mission orientation with reflexive governance and social learning” (Wanzenböck et al., 2020). These concepts can provide productive development in the GHES debate because they are in line with the idea of an agonistic approach as defined by Popa et al. (2021). Aspects of both policy pathways are thus considered useful. A risk for a hybrid policy pathway as defined by Wanzenböck et al. (2020) is that setbacks in the pathway can come from both ‘sides’. Contestation, complexity, and uncertainty can hamper progress both on the problem and solution side. However, Wanzenböck et al. (2020) write, trying out new solutions (GHES) and better comprehending the problem as well as the solution-problem interaction “offers a lot of learning potential”. Practical implications of sociotechnical imaginaries are not only relevant for policy pathways. Wicked problems are not only an aspect of the public sector but are also shaped by private sector influences. Several consensus and conflict items can be identified to try and prevent an “unfounded selection of the ‘best’ solution” (Wanzenböck et al., 2020), which is a threat in the hybrid policy pathway.

5.1. Practical Recommendations

There are several practical implications for industrial actors and policymakers to be formulated. Based on the consensus and conflict items described above, the case for GHES development looks good. This is based on several aspects of the results. Coming down to the desirability of this technology, actors are divided on if it should be the primary means of renewable energy storage (conflict item 2), but also whether a sustainable future cannot be reached without it (consensus item 3). Actors also agree that it should be part of the solution (consensus item 2). Actors have expressed that innovations in electrical storage will not make GHES storage redundant (consensus item 6). Finally, from a safety standpoint, actors feel that using hydrogen is not more dangerous than using fossil fuels (consensus item 7). However, actors are not in agreement if a near-complete reduction of carbon emissions in the energy sector can be obtained through GHES (conflict item 3). But there is consensus that it should be part of the solution thus the actors feel that it could provide some reduction of carbon emissions in the energy sector. What could thus be abandoned according to the respondents are the ideas that GHES should be the primary means of renewable energy storage and the idea that hydrogen can facilitate a near-complete reduction of carbon emissions. According to the respondents, there is consensus on a nuanced place for GHES in the Dutch future energy mix.

Furthermore, practical ways of achieving the development of GHES would be to implement a higher fossil fuel tax as is shown in consensus item 4. Currently, the Netherlands does tax fossil fuels, and the EU has a CO2 emissions trading system (synonym to taxing fossil fuels), but actors agree on increasing these measures to make using fossil fuels more expensive. Actors moreover recognize that technology standards are necessary for the development of GHES (consensus item 5). Reaching technology standards is also a form of contestation which could be reached through market competition or through policy-guided standardization. The EU for example even regulates standardization in Europe to ensure a reliable and safe grid operation (Beck et al., 2022). This type of regulation could for example also be applied to GHES to meet the necessity for technological standardization as expressed by the respondents. Standards for a green hydrogen market are currently being discussed by national and international standardization organizations and policymakers (Velazquez Abad & Dodds, 2020). This type of cooperation is in line with the expression by the respondents of the need for international cooperation. While this is one example, the European Commission is contributing to the global initiative “Mission Innovation” of 23 member states across all continents, focusing on innovation and cooperation efforts across the clean energy spectrum (*International Cooperation in Clean Energy*, n.d.). In 2021, the Mission Innovation member states committed to stronger action, an action that focuses on clean hydrogen as well. It is this type of international cooperation that respondents have shown to agree. A practical implication is thus that there already is alignment between these efforts and the normative ideas of the stakeholders in this study.

Using concepts or notions defined or used by Wanzenböck et al. (2020) (Policy Pathways), Porter and Kramer (2019) (Shared Value), and Popa et al. (2021) (Agonistic Approach to Conflict), could help in formulating further practical implications. These concepts are focused more on conflicts and are thus applied to the conflict items. The problem-led and hybrid policy pathways as defined in Wanzenböck et al. (2020) both provide insight and indicate where the climate change (problem) - GHES (solution) combination currently sits on the solution-problem matrix as defined by Wanzenböck et al. (2020) below in Figure 4. The top arrow represents the problem-led pathway, the middle arrow the hybrid pathway and the bottom arrow represents the solution-led pathway.

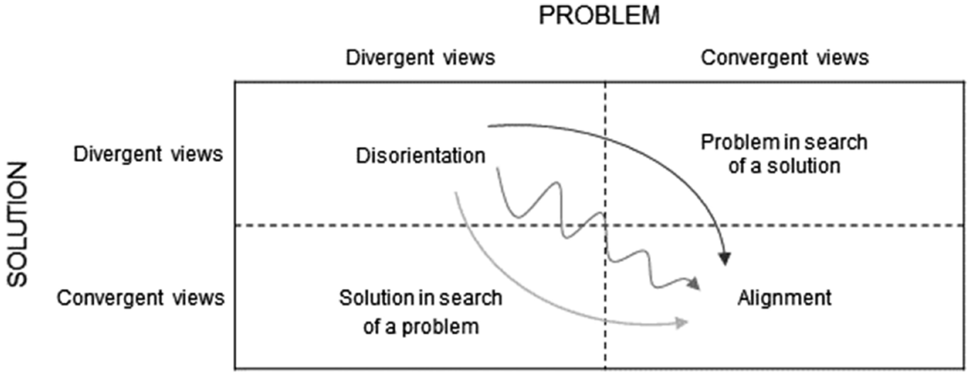

Figure 4 - Different policy pathways (Wanzenböck et al., 2020)

What the figure above shows (in combination with the findings of this study) is whether the climate change (problem) - GHES (solution) combination is viewed as being on the hybrid or problem-led pathway, it is more in the alignment cell (bottom-right) of the matrix. Again, signaling that the case for GHES looks good. But as mentioned above, there are conflict items to overcome. The results showed that the public actors in this study are more inclined to see the role of government, whether in intervention or in guidance, as a solution (conflict item 4). The results also showed that the citizens in this study are more inclined to see economic development as the main priority (conflict item 1). Can these visions be intertwined?

Achieving a healthy dialogue on a long-standing dichotomy (market vs state) could be achieved through social learning (Collins & Ison, 2009) and reflexive governance (Leonard et al., 2021). These two concepts are suggested by Wanzenböck et al. (2020) to form a problem-led policy strategy and are in line with an agonistic approach (Popa et al., 2021). Social learning is centered around one or all of these three aspects: [1] the convergency of goal formulation which leads to mutual understanding and the building of relational capital, and [2] co-creation of knowledge which informs both parties on how to start the GHES transition and [3], the change in attitude that stems from understanding the situation through action (being present during the process) (Collins & Ison, 2009). This approach is coupled with the concept of reflexive governance which is centered around being an answer to neoliberalism in which the dichotomy of market vs state is still strong (Leonard et al., 2021). Reflexive governance is centered around participation and deliberation (Leonard et al., 2021), which is a way of achieving convergency of goal formulation, co-creation of knowledge, and the change in attitude as defined in Collins & Ison (2009). Social learning which achieves reflexive governance could at least in the market-state relationship be a strong method for achieving Porter and Kamer's notion of shared value (Porter & Kramer, 2019). In line with Mazzucato (2011), an entrepreneurial state in cooperation with market players could unite the long-standing dichotomy. The barrier of economic development vs the role of government is critically discussed in the book by Mazzucato. This line of thinking is in accordance with an "agonistic approach to technological conflict" (Popa et al., 2021) as discussed earlier to not "agree to disagree" on the market-state relationship. This approach could at least bring constructive debate on conflict items 1 and 4.

Social implications of the development of GHES are the fifth and final conflict item for discussion. For a meaningful discussion on the social implications, the concerns of this group need to be reiterated. Why are the social implications a concern and what is the trade-off that these respondents believe could compromise the desired social outcomes? First, the statement saying that incumbent energy companies such as Shell and BP would reap most of the benefits was placed most in agreement with of all imaginaries. Second, social acceptance is a barrier to market acceptance of this imaginary. Again, a solution could be in Porter and Kramer's (2019) notion of shared value as it is centered around "identifying and expanding the connections between societal and economic progress" (Porter & Kramer, 2019). Furthermore, public ownership of large-scale hydrogen facilities is seen as a solution of this imaginary. Coming back to the previous point, perhaps a stakeholder dialogue on the market-state relationship could bring consensus by making arguments such as that energy provision is currently for some portion a state matter.

5.2. Theoretical Implications

The theoretical framework provided a lens and thus blind spots for doing this kind of exploratory research. Future visions were identified, although 27 out of 41 respondents significantly loading is less than 3/4 of the sample. This means that more than 1/4 of the sample respondents don't fall into one of the five defined sociotechnical imaginaries. It should be understood that this is within the boundaries set in the research method section. However, the fact that 1/4 of the sample does not significantly load is a problem in relation to sociotechnical imaginaries. Because it possibly indicates that either, imaginaries as a concept are not fully suited to describe the rich diverse normative future visions of GHES, or the concept needs refinement. Thus, speaking of sociotechnical imaginaries, which are "collectively held" (Jasanoff & Kim, 2015) can be done more limited than anticipated. The views on GHES are perhaps too diverse to be fully captured by sociotechnical imaginaries. As was mentioned in the theory section, multiple contested imaginaries are recognized in an article written by Jasanoff & Kim (2015) but more detailed analysis is needed on this particular imaginary. Diversity in imaginaries is thus recognized, but even more, diversity is present in views on GHES. Perhaps a recognition of more diversity in the concept of sociotechnical imaginaries is needed. As said in the introduction quantitatively describing imaginaries using Q method is rather novel with less than ten studies that could be found before January 2022. In one of these studies, Cairns et al. (2022) write that "overlaps and interconnection" and "complexity of relations" is found between the imaginaries. A more person-centered approach instead of the 'collectively held' approach of Jasanoff & Kim might thus be more applicable to imaginaries as this better recognizes the diversity of opinion (Strauss, 2006). What should be noted, as mentioned in the theory section, is that in 2006, Jasanoff & Kim's imaginaries were still defined as "nation-specific" which was later changed to "collectively held". However, the definition and understanding of imaginaries might still be too broad as mentioned by Cairns et al. (2022), thus causing it to miss elements of rich diverse future visions. Jasanoff & Kim (2015), in Dreamscapes of Modernity, describe sociotechnical imaginaries as a rather abstract and inherently qualitative concept. By utilizing Q method to try and find imaginaries, searching for imaginaries is now also quantitatively proven possible. As was already proven by Rodhouse et al (2021), Q method is suited for quantitatively describing imaginaries. By showing that Q method is also suited for describing imaginaries on GHES, the case for using Q method to describe imaginaries becomes stronger. Furthermore, using Q method to describe imaginaries has provided information on the problem-solution spaces as defined by Wanzenböck et al. (2020). The results have shown that the climate change (problem) GHES (solution) combination is either on the hybrid and/or problem-led policy pathway. Providing insight into this wicked problem is thus possible using Q method by describing coherent future visions. Part of this insight is that contestation (one of the three characteristics of wicked problems) is richer than only the five defined imaginaries because of the not loading respondents. Additionally, wicked problems are sometimes seen as a 'black box', "whose inner mechanism constitutes a mystery" (Alford & Head, 2017). Q method can thus be used to partially see inside this black box.

To quote Watts & Stenner (2012), Q methodological results should be generalized to the whole population with "great care". For speculative purposes, the assumption is thus now made that the views of private sectors actors in this study are representative of the population of private sector actors. What this means is there is a division on future visions for GHES in the private sector. As can be seen in Appendix 2, seven out of ten private sector respondents load on one of the factors. Four on the first factor, and one on factors 2, 3, and 4. Adding to this, there are three respondents who do not load on any of the factors. An implication of this is that creating shared value as defined by Porter and Kramer (2019) is hampered. One way to achieve shared value is through the utilization of open innovation (Chaurasia et al., 2020). Private sector actors would benefit from open innovation when it is helped by shared future visions (Chaurasia et al., 2020). This is currently not the case in the population when adhering to the assumption above. Furthermore, the concept of shared value through open innovation is, according to Chaurasia et al. (2020), not yet implemented or utilized enough in the current private sector. This also hampers efforts for policymakers as policy is harder to write for divided market actors. What could be one of the causes is the inability of the literature to convey the method and benefits of shared value creation through open innovation. There lies a challenge in uniting purpose among private sector actors. This goes beyond the practical implications such as agreement on technology standards or the agreement on higher fossil fuel taxes.

5.3. Limitations and Further Research

Exploratory research comes with its limitations, as does a master thesis and Q methodology. First, as written in Watts and Stenner (2012), an interpretation of a factor is just that. The researcher has taken great care in the process to be as unbiased and objective as possible. What is inevitable is that the factor interpretation is a reflection to some degree of the unknown preconceptions of the researcher. To combat this, thematic analysis as defined by Nowel et al. (2017) was incorporated into the research design. As mentioned in the research method chapter, thematic analysis is centered around reflexivity and documentation of choices. An example of documentation of choices is an audit trail as defined by Nowel et al. (2017), a separate document where notes were taken that were incorporated into this report. Second, what should be understood is that Q methodological results should be generalized to the whole population with "great care" (Watts & Stenner, 2012). In other words, the results can be interpreted as an indication of the sociotechnical imaginaries of the population but should not be assumed to be so.

Third, the relative nature of Q method in combination with the inability to take interviews during the sorting by the respondents is a limitation. What is meant by relativity is the inability to verify if a respondent is indifferent about a statement which is placed on [0]. If it were possible to put interviews in scope, a reference point of somebody's future perspective could have been identified. Interviews could not be put into scope because of the limited time available for doing a master thesis. Furthermore, email contact was not possible during the analysis part because the number of respondents (effectively all significantly loading respondents) that then had to be contacted was too high and the communication would be too elaborate. To illustrate this point statements 25 and 26 were placed in consensus as indifferent by most of the respondents who significantly loaded. Additionally, most respondents placed "Climate change concerns me" on [+5]. The statement could mean multiple things to different actors, the social consequences for populations in the most hard-hit areas could be concerning, or the uncertainty of the future reliability of food supply for the Netherlands. Finally, during the analysis, the professional role of the respondent was interesting, but getting to know more also involved finding out pro-government or government-critical preferences. A topic not easily discussed over email. These interactions are best discussed in an interview with the respondents, but this should then be done via email (sub-optimal solution). In conclusion, emailing with the respondents was going to take more time than is in scope for a master thesis with the downside of email not being suited for discussions on political preferences. Keeping the ambiguity of interpretation was considered to suffice given that reducing this ambiguity would have caused planning problems. Fourth, 35 statements on GHES is a rich concourse on the subject but it does not encompass all future visions present in the current discourse. For example, respondents did not have the chance to give their opinion on current hydrogen projects such as NortH2, a large-scale hydrogen project in Groningen, the Netherlands (*NortH2 | Kickstarting the Green Hydrogen Economy*, n.d.). Another example is that no statements in the concourse place GHES as a solution to Europe's Russian fossil fuel dependence. This is also due to the publication dates of the articles used for concourse development being around a year before the start of the war in Ukraine. A richer set of statements would provide a more complete image of the imaginaries currently present on GHES. Fifth, the scope of a master thesis has its further limitations, besides not being able to take interviews. It was not possible to analyze the Q sort of the respondents that did not load on any of the factors. The point was made earlier that sociotechnical imaginaries could recognize more diverse future visions as there are more present in this study than the five defined imaginaries.

A direction for further research would thus first be, to analyze the Q sorts of non-loading respondents and to see what the diverse future visions on GHES entail. The second is to study the shortcomings of the industry to implement open innovation practices to achieve shared value. Is it because of the inability of the literature to convey the method and benefits of shared value creation through open innovation? A lot of focus in this study is on academic concepts which can normatively guide transitions but if the notions brought forward by academics are not implemented, progress will not be made. The industry could thus also be lacking in implementing these concepts, what is causing this? Third and finally, a direction for further research could be to try and place the results in a different social concept, as imaginaries seem to fall short in describing the normative conflicting and desired futures. Aspects of the longer-standing future studies or foresight methods could provide meaningful insight into GHES futures. Foresight is defined as "a process by which one comes to a fuller understanding of the forces shaping the long-term future which should be taken into account in policy formulation, planning, and decision-making" (Martin, 2010). Sociotechnical imaginaries could be understood to fall under the umbrella of foresight studies. What should be understood is that foresight studies have been defined and have been around since the 1980s (Martin, 2010). Meaning that a rich field of foresight concepts and methods is available for learning about desired normative futures on GHES, such as 'normative scenarios' (Skea et al., 2021), which recognize more diversity.

6. Conclusion

The research question is formulated as: “What are the different sociotechnical imaginaries of green hydrogen energy storage (GHES) in the Netherlands?” Stakeholders involved with or in GHES have shown to have diverged future visions on GHES. Five perspectives were identified using Q method. Fourteen respondents, out of 41, did not significantly load on any of these five perspectives, showing the diversity of opinion on GHES. Q method is thus suited for the description of future coinciding and conflicting visions (sociotechnical imaginaries) on GHES for around 3/4 of the sample respondents. The relative nature of Q method in combination with the study limitations should be considered when reading the interpretations. The imaginaries have been named: [1] “We are hydrogen-optimistic and critically realistic”, [2] “Hydrogen: a driver for economic opportunity”, [3] “We’re not excited”, [4] “Welcome state intervention”, and [5] “Hydrogen storage is the way to go but be aware of big industry”. The first imaginary mainly describes how hydrogen should be a part of the energy mix, not the sole solution. The second imaginary emphasizes the economic opportunity that GHES can have with a strong emphasis on cooperation between parties. The third imaginary shows that there are respondents who feel concerned for climate change, but don’t see hydrogen as a solution at all. The fourth imaginary sees government intervention as the only way to facilitate this transition. The final imaginary shows that there is a concern for social implications on who will benefit from the transition towards GHES. In extension and to fulfill the research aim, practical and theoretical implications are formulated to better align the technology/energy carrier combination to the normative ideas of stakeholders. According to the respondents, the case looks promising for GHES as there is agreement on GHES becoming a part of the Dutch energy mix. Methods of achieving this goal, according to the results are e.g., a higher fossil fuel tax, development of technology standards, and the need for international cooperation. Moreover, conflict items are defined, as is also the goal of Q method, the degree of the focus of economic development, the role of the government to guide and intervene, and the focus on the social implications of the transition towards GHES. These conflict items could be addressed according to an agonistic approach by utilizing social learning and reflexive governance. These practices have gained eminence and are becoming more accepted. Furthermore, the climate change (problem) - GHES (solution) combination was recognized to show characteristics of a hybrid policy pathway and the problem-led policy pathway. These two pathways provide insight into how to gain information on the wickedness of the problem and if GHES is one of the solutions. Social learning and reflexive governance are examples of this. For the theoretical implications, sociotechnical imaginaries as a concept fall short of describing the normative future visions as expressed by the respondents. Other scholars have also recognized that the concept might miss diversity in future visions because of its singular interpretation. However, it has been proven possible to, in a quantitative manner (using Q method), describe the sociotechnical imaginaries of around 3/4 of the respondents. Another implication is that it is also possible to use Q-method to peek in the ‘black box’ of wicked problems. The results show that conflicting visions about the future could be better understood in the context of contestation, uncertainty, and complexity (in other words; wicked problems). Moreover, according to the results, private sector actors are divided on their views of GHES, meaning that shared value creation using open innovation is problematic. This also hampers efforts for policymakers. An alignment of normative future visions or even a possibility of open innovation without such an alignment is designated as a direction for future research. Furthermore, given the scope of a master thesis, analyzing the Q sorts of the respondents that did not load on any of the factors provides insight onto the diversity of normative future visions. Finally, the results of this study could be placed in a different social concept such as one of the concepts in the rich umbrella of foresight studies. An example being so-called ‘normative scenarios’ which recognizes more diversity.

7. Reflection

Writing a thesis on an academic level has been an immensely enjoyable experience. A steep learning curve has been made in doing academic research. It has been a great pleasure to learn so much about this topic. For example, truly understanding what an academic paper tries to convey is always a challenge, but can, even more, be so for a student. Feedback was given on, for example, an interpretation of an article by Cuppen et al. (2010) which says the opposite of what was taken away and written in the method section. Another example is the article by Gannon et al. (2022) which was used to learn how to find sociotechnical imaginaries using Q method. Upon more careful reading of the article after feedback that was provided, it turns out that the concept of sociotechnical imaginaries was misinterpreted by the authors. This conveys a broader lesson for me which is to be critical of information, even when it is published by academics. This lesson was learned later in the thesis while it would have been valuable to be more competent in this skill during concourse development. Developing a concourse by the careful reading of 10 articles requires immense attention to detail in combination with critical reading. A limitation of this study could then also be that this competency was not fully mature at the time of concourse development which is early on in the thesis. Another interesting point of discussion during the green-light meeting was the generalization of Q methodological results. Upon more in-depth reading of Watts & Stenner (2012), it turns out that generalizations are more common or better possible on conceptual grounds. This message was clear to me personally, but it was poorly reported. The point made is that substantial gains have been made in judging information as well as how to report that information. Although I can still further learn about these two aspects, these are very valuable given my new job as a consultant.

What I would like to do differently next time is the amount of contact that was maintained with the respondents. Watts & Stenner (2012) argue that at least some contact is needed to obtain a reference point of somebody's opinion during or after Q sorting. This would have created academic value, also given that the goal is to publish the research in a paper. Furthermore, a skill that I would like to further develop is being more organized. I mean this in the sense of preparation for e.g. writing the discussion, an aspect that was new to me. There is plenty of information to be found on how to write a discussion but for some reason, I started writing the discussion according to my own idea of how it be. Taking a step back instead of multiple steps forward when it is necessary is invaluable.

Also mentioned in the preface of the thesis and at the beginning of this review is the fact that writing this thesis was an immensely enjoyable experience. I have learned, in cooperation, how to come up with a research topic and how to shape and execute the research. Coming from a fuzzy idea I had almost a year ago to a finalized report has been interesting and very fulfilling. Cooperating with some very knowledgeable and skilled academics has been very enjoyable. At times when I had questions, a meeting was planned swiftly and within a short timeframe. An atmosphere was created which enabled free discussion of ideas together with a productive setting to come to what I believe is a solid research design and research topic. In the execution of that research design, there is no better way of supervising a thesis student than has been done in these last few months. It must be said that I could not have written a report on the same level as it is now without the help and supervision of Neelke Doorn, Geerten van de Kaa, and Martijn Wiarda.

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Appendices

1. Appendix – Statements

No	Statement	Source	Category
1	Universal technology standards are not necessary for the development of hydrogen energy storage.	Self-made	Technical
2	Underground hydrogen storage is an undesirable technology in the Netherlands.	Self-made	Social
3	Climate change concerns me.	Fazioli 2021	Social
4	Public ownership of large-scale hydrogen storage is not necessary for future market acceptance of green hydrogen.	Saccani 2020	Social
5	Social acceptance is one of the most critical barriers for success of hydrogen storage.	Saccani 2020	Social
6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	Gurrief 2021	Technical
7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	Koneczna 2021	Technical
8	Hydrogen needs to become the primary means of renewable energy storage.	Oliveira 2021	Technical
9	The considerable energy losses of conversion processes will limit the use of hydrogen.	Oliveira 2021	Technical
10	A sustainable future can be accomplished without hydrogen technologies for energy conversion and storage.	Oliveira 2021	Technical
11	Hydrogen will be especially important in the energy sector.	Oliveira 2021	Technical
12	Green hydrogen is but one of the many renewable energy solutions that we need to accomplish our climate change mitigation goals.	Oliveira 2021	Technical
13	Situations of "excess renewable energy" will not occur frequently enough to justify large investments in intermittent electrolysis.	Wanner 2021	Technical
14	By 2030, green hydrogen will be commercially competitive with fossil fuel-based forms of hydrogen.	Calado 2021	Economic
15	Domestic green hydrogen production will have a marginal effect on the Dutch economy.	Fazioli 2021	Economic
16	Green hydrogen storage technologies should only be developed if there is an economically viable business case.	Fazioli 2021	Economic
17	Because of the speed of climate change, we do not have the luxury of waiting for hydrogen technologies to become cost competitive.	Gurrief 2021	Economic
18	Based on its current leadership position in gray hydrogen production, the Netherlands should aim to become one of the biggest green hydrogen producers in Europe.	Koneczna 2021	Economic
19	Cost efficiency of hydrogen technologies can only be marginally improved via innovation.	Koneczna 2021	Economic

20	Incumbent energy companies like Shell and BP stand to gain most from the move towards hydrogen.	Koneczna 2021	Economic
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Calado 2021	Political/economic
22	We should turn the Netherlands into a pioneering country when it comes to hydrogen energy storage technologies.	Koneczna 2021	Political/economic
23	The government should intervene as little as possible in the currently developing hydrogen market.	Self-made	Political
24	The purchase of green hydrogen energy storage technologies should be stimulated by a tax break.	Saccani 2020	Political/economic
25	The recent EU ambitions to accelerate the development of European renewable energy production capacity are insufficiently thought through in relation to hydrogen.	Caglayan 2021	Political
26	The EU should demonstrate more interest in green hydrogen energy storage.	Koneczna 2021	Political
27	Europe must become the world leader in electrolyser technology.	Koneczna 2021	Political
28	International cooperation is not needed for the development of green hydrogen energy storage technologies.	Koneczna 2021	Political
29	We need more clear policies and regulations on the possibilities of hydrogen conversion and system integration.	Koneczna 2021	Political
30	To encourage the development of hydrogen storage technologies, we need dynamic and open regulations that allow for cooperation rather than competition.	Saccani 2020	Political
31	The future use of hydrogen is more dangerous than the use of fossil fuels.	Capurso 2022	Safety
32	We need to consider the potential negative effects of hydrogen implementation more (e.g. safety, environmental issues, etc.).	Capurso 2022	Safety
33	Innovations in electrical storage could make green hydrogen redundant.	Self-made	Technical
34	There will be better - cheaper, and easier - methods of energy storage than green hydrogen.	Self-made	Technical
35	The Netherlands should become a major hydrogen import and trade hub because of its many strategic advantages, such as its existing infrastructure and underground hydrogen storage potential.	Self-made	Economic

2. Appendix – Respondent Loadings on Factors

Professional roles are made bold if the respondents significantly load on any of the factors. The professional roles are alphabetically sorted.

Professional	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Academic	0.33546	-0.01521	**0.57561***	0.34407	-0.28987
Academic	-0.09394	-0.17241	**0.43495***	-0.02806	0.0037
Academic	-0.07829	**0.59781***	0.02883	0.1574	-0.02162
Academic	0.08539	0.17175	-0.18859	0.28952	**0.54862***
Academic	**0.65777***	0.18897	0.26343	0.14378	0.12707
Academic	0.29324	0.20173	0.20911	0.43315	0.30386
Academic	0.59027	0.35958	0.00904	0.52001	0.31337
Academic	0.48641	0.46114	0.05845	0.19875	0.18434
Citizen	-0.00468	-0.07701	0.17358	**0.79514***	0.22618
Citizen	0.23031	**0.76672***	0.01291	0.02889	0.19982
Citizen	**0.49221***	0.28696	0.01541	0.05182	0.37702
Citizen	0.19517	**0.601***	-0.34099	0.25262	0.00881
Citizen	0.34996	0.34386	0.17263	**0.54876***	0.12575
Citizen	0.00931	**0.53505***	-0.10807	0.03688	-0.07951
Citizen	0.10745	**0.51667***	0.05097	0.1913	0.24306
Citizen	0.16885	**0.57623***	-0.09861	0.22816	0.14177
Citizen	0.37233	-0.06793	-0.0959	-0.00509	**0.4456***
Citizen	0.50951	0.42308	0.30552	0.44835	0.07504
Citizen	0.20307	0.40629	0.31584	0.40653	0.05763
Citizen	0.33048	0.57001	0.17792	0.25717	0.54279
Citizen	0.44331	0.53137	0.38148	0.20018	0.07775
Private	**0.73815***	-0.13262	-0.20792	0.19308	0.16746
Private	0.28664	0.36461	-0.17644	**0.55759***	0.01711
Private	0.09981	**0.50822***	0.28494	0.17981	0.13354
Private	**0.47572***	0.08362	0.06585	0.15995	0.02124
Private	0.29932	0.17778	**0.51033***	0.01855	-0.15336

Private	**0.60896***	0.3	-0.11832	0.42724	0.17758
Private	**0.59715***	0.2133	0.35798	0.02543	0.08751
Private	0.18141	0.57163	0.25595	0.3187	0.45317
Private	0.48778	0.53502	0.15602	0.16185	0.00753
Private	0.32251	0.41301	0.42853	0.34902	0.16189
Public	0.48078	0.28604	-0.00485	**0.65942***	0.05133
Public	**0.65172***	-0.15009	0.25206	0.45025	0.07055
Public	0.00705	0.00846	**0.55734***	0.09587	0.0366
Public	0.14337	0.31559	0.05585	**0.59975***	0.05955
Public	0.32675	0.32409	0.1573	**0.50183***	-0.02211
Public	0.43916	0.23173	-0.02231	**0.51203***	0.03015
Public	0.51313	0.48134	0.08255	0.35422	0.18873
Public	0.18154	0.32878	0.37127	0.57383	0.38471
Public	0.50119	0.41211	0.19185	0.40509	0.42455
Public	0.49955	0.3332	-0.06649	0.39115	0.1142

3. Appendix – Sort Values

No	Statement	F1	F2	F3	F4	F5
1	Universal technology standards are not necessary for the development of hydrogen energy storage.	-1	-4	-3	-4	-1
2	Underground hydrogen storage is an undesirable technology in the Netherlands	-3	-1	-2	-3	-2
3	Climate change concerns me.	5	0	5	5	1
4	Public ownership of large-scale hydrogen storage is not necessary for future market acceptance of green hydrogen.	-1	0	1	-2	-3
5	Social acceptance is one of the most critical barriers for success of hydrogen storage.	-1	-1	1	-1	4
6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	-2	2	-5	1	0
7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	2	4	-3	0	2
8	Hydrogen needs to become the primary means of renewable energy storage.	-2	1	-4	0	5
9	The considerable energy losses of conversion processes will limit the use of hydrogen.	3	-2	2	-1	3
10	A sustainable future can be accomplished without hydrogen technologies for energy conversion and storage.	-4	-2	4	-1	-2
11	Hydrogen will be especially important in the energy sector.	-5	1	1	1	-1
12	Green hydrogen is but one of the many renewable energy solutions that we need to accomplish our climate change mitigation goals.	4	1	3	3	0
13	Situations of "excess renewable energy" will not occur frequently enough to justify large investments in intermittent electrolysis.	1	-3	-2	-1	2
14	By 2030, green hydrogen will be commercially competitive with fossil fuel-based forms of hydrogen.	0	1	-1	1	-1
15	Domestic green hydrogen production will have a marginal effect on the Dutch economy.	0	-2	-2	0	2
16	Green hydrogen storage technologies should only be developed if there is an economically viable business case.	-3	-1	1	-2	-4
17	Because of the speed of climate change, we do not have the luxury of waiting for hydrogen technologies to become cost competitive.	3	0	1	4	1
18	Based on its current leadership position in gray hydrogen production, the Netherlands should aim to become one of the biggest green hydrogen producers in Europe.	-1	3	0	-5	-3
19	Cost efficiency of hydrogen technologies can only be marginally improved via innovation.	0	-5	-1	-4	-2
20	Incumbent energy companies like Shell and BP stand to gain most from the move towards hydrogen.	1	-1	0	-2	2
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	4	3	3	3	3
22	We should turn the Netherlands into a pioneering country when it comes to hydrogen energy storage technologies.	2	5	-3	2	1
23	The government should intervene as little as possible in the currently developing hydrogen market.	-2	2	0	-3	-1
24	The purchase of green hydrogen energy storage technologies should be stimulated by a tax break.	2	2	-1	2	1

25	The recent EU ambitions to accelerate the development of European renewable energy production capacity are insufficiently thought through in relation to hydrogen.	0	0	-1	0	0
26	The EU should demonstrate more interest in green hydrogen energy storage.	1	1	2	1	3
27	Europe must become the world leader in electrolyzer technology.	1	3	-1	1	4
28	International cooperation is not needed for the development of green hydrogen energy storage technologies.	-3	-3	-4	-1	0
29	We need more clear policies and regulations on the possibilities of hydrogen conversion and system integration.	2	0	4	4	-2
30	To encourage the development of hydrogen storage technologies, we need dynamic and open regulations that allow for cooperation rather than competition.	1	4	3	3	1
31	The future use of hydrogen is more dangerous than the use of fossil fuels.	-4	-3	-2	-2	-4
32	We need to consider the potential negative effects of hydrogen implementation more (e.g. safety, environmental issues, etc.).	-2	-1	2	2	0
33	Innovations in electrical storage could make green hydrogen redundant.	-1	-4	2	-3	-1
34	There will be better - cheaper, and easier - methods of energy storage than green hydrogen.	0	-2	0	0	-5
35	The Netherlands should become a major hydrogen import and trade hub because of its many strategic advantages, such as its existing infrastructure and underground hydrogen storage potential.	3	2	0	2	-3

4. Appendix – Crib Sheets

4.1. Crib Sheet Factor 1

No	Statement	Category	Sort values
Distinguishing Statements for Factor 1			
12	Green hydrogen is but one of the many renewable energy solutions that we need to accomplish our climate change mitigation goals.	Technical	4
4	Public ownership of large-scale hydrogen storage is not necessary for future market acceptance of green hydrogen.	Social	-1
6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	Technical	-2
11	Hydrogen will be especially important in the energy sector.	Technical	-5
Consensus Statements for Factor 1			
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/ economic	4
25	The recent EU ambitions to accelerate the development of European renewable energy production capacity are insufficiently thought through in relation to hydrogen.	Political	0
2	Underground hydrogen storage is an undesirable technology in the Netherlands.	Social	-3
Most Characteristic			
3	Climate change concerns me.	Social	5
12	Green hydrogen is but one of the many renewable energy solutions that we need to accomplish our climate change mitigation goals.	Technical	4
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/ economic	4
17	Because of the speed of climate change, we do not have the luxury of waiting for hydrogen technologies to become cost competitive.	Economic	3
9	The considerable energy losses of conversion processes will limit the use of hydrogen.	Technical	3
35	The Netherlands should become a major hydrogen import and trade hub because of its many strategic advantages, such as its existing infrastructure and underground hydrogen storage potential.	Economic	3
Most Uncharacteristic			
2	Underground hydrogen storage is an undesirable technology in the Netherlands.	Technical	-3
28	International cooperation is not needed for the development of green hydrogen energy storage technologies.	Political	-3
16	Green hydrogen storage technologies should only be developed if there is an economically viable business case.	Economic	-3
31	The future use of hydrogen is more dangerous than the use of fossil fuels.	Safety	-4
10	A sustainable future can be accomplished without hydrogen technologies for energy conversion and storage.	Technical	-4
11	Hydrogen will be especially important in the energy sector.	Technical	-5
Quite Characteristic			
22	We should turn the Netherlands into a pioneering country when it comes to hydrogen energy storage technologies.	Political/ economic	2

7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	Technical	2
24	The purchase of green hydrogen energy storage technologies should be stimulated by a tax break.	Political/ economic	2
29	We need more clear policies and regulations on the possibilities of hydrogen conversion and system integration.	Political	2
30	To encourage the development of hydrogen storage technologies, we need dynamic and open regulations that allow for cooperation rather than competition.	Political	1
27	Europe must become the world leader in electrolyser technology.	Political	1
20	Incumbent energy companies like Shell and BP stand to gain most from the move towards hydrogen.	Economic	1
26	The EU should demonstrate more interest in green hydrogen energy storage.	Political	1
13	Situations of "excess renewable energy" will not occur frequently enough to justify large investments in intermittent electrolysis.	Technical	1
Quite Uncharacteristic			
33	Innovations in electrical storage could make green hydrogen redundant.	Technical	-1
4	Public ownership of large-scale hydrogen storage is not necessary for future market acceptance of green hydrogen.	Social	-1
18	Based on its current leadership position in gray hydrogen production, the Netherlands should aim to become one of the biggest green hydrogen producers in Europe.	Economic	-1
1	Universal technology standards are not necessary for the development of hydrogen energy storage.	Technical	-1
5	Social acceptance is one of the most critical barriers for success of hydrogen storage.	Social	-1
32	We need to consider the potential negative effects of hydrogen implementation more (e.g. safety, environmental issues, etc.).	Safety	-2
6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	Technical	-2
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	-2
23	The government should intervene as little as possible in the currently developing hydrogen market.	Political	-2

4.2. Crib Sheet Factor 2

No	Statement	Category	Sort values
Distinguishing Statements for Factor 2			
18	Based on its current leadership position in gray hydrogen production, the Netherlands should aim to become one of the biggest green hydrogen producers in Europe.	Economic	3
23	The government should intervene as little as possible in the currently developing hydrogen market.	Political	2
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	1
34	There will be better - cheaper, and easier - methods of energy storage than green hydrogen.	Technical	-2
19	Cost efficiency of hydrogen technologies can only be marginally improved via innovation.	Economic	-5
Consensus Statements for Factor 2			
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/economic	3
25	The recent EU ambitions to accelerate the development of European renewable energy production capacity are insufficiently thought through in relation to hydrogen.	Political	0
Most Characteristic			
22	We should turn the Netherlands into a pioneering country when it comes to hydrogen energy storage technologies.	Political/economic	5
7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	Technical	4
30	To encourage the development of hydrogen storage technologies, we need dynamic and open regulations that allow for cooperation rather than competition.	Political	4
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/economic	3
27	Europe must become the world leader in electrolyzer technology.	Political	3
18	Based on its current leadership position in gray hydrogen production, the Netherlands should aim to become one of the biggest green hydrogen producers in Europe.	Economic	3
Most Uncharacteristic			
31	The future use of hydrogen is more dangerous than the use of fossil fuels.	Safety	-3
13	Situations of "excess renewable energy" will not occur frequently enough to justify large investments in intermittent electrolysis.	Technical	-3
28	International cooperation is not needed for the development of green hydrogen energy storage technologies.	Political	-3
33	Innovations in electrical storage could make green hydrogen redundant.	Technical	-4
1	Universal technology standards are not necessary for the development of hydrogen energy storage.	Technical	-4
19	Cost efficiency of hydrogen technologies can only be marginally improved via innovation.	Economic	-5
Quite Characteristic			

24	The purchase of green hydrogen energy storage technologies should be stimulated by a tax break.	Political/economic	2
6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	Technical	2
35	The Netherlands should become a major hydrogen import and trade hub because of its many strategic advantages, such as its existing infrastructure and underground hydrogen storage potential.	Economic	2
23	The government should intervene as little as possible in the currently developing hydrogen market.	Political	2
26	The EU should demonstrate more interest in green hydrogen energy storage.	Political	1
11	Hydrogen will be especially important in the energy sector.	Technical	1
14	By 2030, green hydrogen will be commercially competitive with fossil fuel-based forms of hydrogen.	Economic	1
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	1
12	Green hydrogen is but one of the many renewable energy solutions that we need to accomplish our climate change mitigation goals.	Technical	1
Quite Uncharacteristic			
5	Social acceptance is one of the most critical barriers for success of hydrogen storage.	Social	-1
20	Incumbent energy companies like Shell and BP stand to gain most from the move towards hydrogen.	Economic	-1
32	We need to consider the potential negative effects of hydrogen implementation more (e.g. safety, environmental issues, etc.).	Safety	-1
16	Green hydrogen storage technologies should only be developed if there is an economically viable business case.	Economic	-1
2	Underground hydrogen storage is an undesirable technology in the Netherlands	Social	-1
34	There will be better - cheaper, and easier - methods of energy storage than green hydrogen.	Technical	-2
9	The considerable energy losses of conversion processes will limit the use of hydrogen.	Technical	-2
15	Domestic green hydrogen production will have a marginal effect on the Dutch economy.	Economic	-2
10	A sustainable future can be accomplished without hydrogen technologies for energy conversion and storage.	Technical	-2

4.3. Crib Sheet Factor 3

No	Statement	Category	Sort values
Distinguishing Statements for Factor 3			
10	A sustainable future can be accomplished without hydrogen technologies for energy conversion and storage.	Technical	4
33	Innovations in electrical storage could make green hydrogen redundant.	Technical	2
16	Green hydrogen storage technologies should only be developed if there is an economically viable business case.	Economic	1
27	Europe must become the world leader in electrolyzer technology.	Political	-1
22	We should turn the Netherlands into a pioneering country when it comes to hydrogen energy storage technologies.	Political/economic	-3
7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	Technical	-3
28	International cooperation is not needed for the development of green hydrogen energy storage technologies.	Political	-4
6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	Technical	-5
Consensus Statements for Factor 3			
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/economic	3
25	The recent EU ambitions to accelerate the development of European renewable energy production capacity are insufficiently thought through in relation to hydrogen.	Political	-1
Most Characteristic			
3	Climate change concerns me.	Social	5
29	We need more clear policies and regulations on the possibilities of hydrogen conversion and system integration.	Political	4
10	A sustainable future can be accomplished without hydrogen technologies for energy conversion and storage.	Technical	4
12	Green hydrogen is but one of the many renewable energy solutions that we need to accomplish our climate change mitigation goals.	Technical	3
30	To encourage the development of hydrogen storage technologies, we need dynamic and open regulations that allow for cooperation rather than competition.	Political	3
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/economic	3
Most Uncharacteristic			
22	We should turn the Netherlands into a pioneering country when it comes to hydrogen energy storage technologies.	Political/economic	-3
1	Universal technology standards are not necessary for the development of hydrogen energy storage.	Technical	-3
7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	Technical	-3
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	-4
28	International cooperation is not needed for the development of green hydrogen energy storage technologies.	Political	-4

6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	Technical	-5
Quite Characteristic			
9	The considerable energy losses of conversion processes will limit the use of hydrogen.	Technical	2
33	Innovations in electrical storage could make green hydrogen redundant.	Technical	2
26	The EU should demonstrate more interest in green hydrogen energy storage.	Political	2
32	We need to consider the potential negative effects of hydrogen implementation more (e.g. safety, environmental issues, etc.).	Safety	2
16	Green hydrogen storage technologies should only be developed if there is an economically viable business case.	Economic	1
4	Public ownership of large-scale hydrogen storage is not necessary for future market acceptance of green hydrogen.	Social	1
11	Hydrogen will be especially important in the energy sector.	Technical	1
17	Because of the speed of climate change, we do not have the luxury of waiting for hydrogen technologies to become cost competitive.	Economic	1
5	Social acceptance is one of the most critical barriers for success of hydrogen storage.	Social	1
Quite Uncharacteristic			
24	The purchase of green hydrogen energy storage technologies should be stimulated by a tax break.	Political/economic	-1
25	The recent EU ambitions to accelerate the development of European renewable energy production capacity are insufficiently thought through in relation to hydrogen.	Political	-1
27	Europe must become the world leader in electrolyzer technology.	Political	-1
19	Cost efficiency of hydrogen technologies can only be marginally improved via innovation.	Economic	-1
14	By 2030, green hydrogen will be commercially competitive with fossil fuel-based forms of hydrogen.	Economic	-1
13	Situations of "excess renewable energy" will not occur frequently enough to justify large investments in intermittent electrolysis.	Technical	-2
2	Underground hydrogen storage is an undesirable technology in the Netherlands	Social	-2
31	The future use of hydrogen is more dangerous than the use of fossil fuels.	Safety	-2
15	Domestic green hydrogen production will have a marginal effect on the Dutch economy.	Economic	-2

4.4. Crib Sheet Factor 4

No	Statement	Category	Sort values
Distinguishing Statements for Factor 4			
17	Because of the speed of climate change, we do not have the luxury of waiting for hydrogen technologies to become cost competitive.	Economic	4
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	0
7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	Technical	0
Consensus Statements for Factor 4			
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/ economic	3
30	To encourage the development of hydrogen storage technologies, we need dynamic and open regulations that allow for cooperation rather than competition.	Political	3
26	The EU should demonstrate more interest in green hydrogen energy storage.	Political	1
25	The recent EU ambitions to accelerate the development of European renewable energy production capacity are insufficiently thought through in relation to hydrogen.	Political	0
Most Characteristic			
3	Climate change concerns me.	Social	5
17	Because of the speed of climate change, we do not have the luxury of waiting for hydrogen technologies to become cost competitive.	Economic	4
29	We need more clear policies and regulations on the possibilities of hydrogen conversion and system integration.	Political	4
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/ economic	3
12	Green hydrogen is but one of the many renewable energy solutions that we need to accomplish our climate change mitigation goals.	Technical	3
30	To encourage the development of hydrogen storage technologies, we need dynamic and open regulations that allow for cooperation rather than competition.	Political	3
Most Uncharacteristic			
23	The government should intervene as little as possible in the currently developing hydrogen market.	Political	-3
33	Innovations in electrical storage could make green hydrogen redundant.	Technical	-3
2	Underground hydrogen storage is an undesirable technology in the Netherlands	Social	-3
19	Cost efficiency of hydrogen technologies can only be marginally improved via innovation.	Economic	-4
1	Universal technology standards are not necessary for the development of hydrogen energy storage.	Technical	-4
18	Based on its current leadership position in gray hydrogen production, the Netherlands should aim to become one of the biggest green hydrogen producers in Europe.	Economic	-5
Quite Characteristic			

22	We should turn the Netherlands into a pioneering country when it comes to hydrogen energy storage technologies.	Political/ economic	2
24	The purchase of green hydrogen energy storage technologies should be stimulated by a tax break.	Political/ economic	2
32	We need to consider the potential negative effects of hydrogen implementation more (e.g. safety, environmental issues, etc.).	Safety	2
35	The Netherlands should become a major hydrogen import and trade hub because of its many strategic advantages, such as its existing infrastructure and underground hydrogen storage potential.	Economic	2
26	The EU should demonstrate more interest in green hydrogen energy storage.	Political	1
11	Hydrogen will be especially important in the energy sector.	Technical	1
6	Hydrogen can facilitate a near-complete reduction of carbon emissions in the energy sector.	Technical	1
27	Europe must become the world leader in electrolyzer technology.	Political	1
14	By 2030, green hydrogen will be commercially competitive with fossil fuel-based forms of hydrogen.	Economic	1
Quite Uncharacteristic			
13	Situations of "excess renewable energy" will not occur frequently enough to justify large investments in intermittent electrolysis.	Technical	-1
28	International cooperation is not needed for the development of green hydrogen energy storage technologies.	Political	-1
5	Social acceptance is one of the most critical barriers for success of hydrogen storage.	Social	-1
9	The considerable energy losses of conversion processes will limit the use of hydrogen.	Technical	-1
10	A sustainable future can be accomplished without hydrogen technologies for energy conversion and storage.	Technical	-1
20	Incumbent energy companies like Shell and BP stand to gain most from the move towards hydrogen.	Economic	-2
31	The future use of hydrogen is more dangerous than the use of fossil fuels.	Safety	-2
16	Green hydrogen storage technologies should only be developed if there is an economically viable business case.	Economic	-2
4	Public ownership of large-scale hydrogen storage is not necessary for future market acceptance of green hydrogen.	Social	-2

4.5. Crib Sheet Factor 5

No	Statement	Category	Sort values
Distinguishing Statements for Factor 5			
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	5
5	Social acceptance is one of the most critical barriers for success of hydrogen storage.	Social	4
15	Domestic green hydrogen production will have a marginal effect on the Dutch economy.	Economic	2
11	Hydrogen will be especially important in the energy sector.	Technical	-1
29	We need more clear policies and regulations on the possibilities of hydrogen conversion and system integration.	Political	-2
35	The Netherlands should become a major hydrogen import and trade hub because of its many strategic advantages, such as its existing infrastructure and underground hydrogen storage potential.	Economic	-3
34	There will be better - cheaper, and easier - methods of energy storage than green hydrogen.	Technical	-5
Consensus Statements for Factor 5			
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/ economic	3
24	The purchase of green hydrogen energy storage technologies should be stimulated by a tax break.	Political/ economic	1
25	The recent EU ambitions to accelerate the development of European renewable energy production capacity are insufficiently thought through in relation to hydrogen.	Political	0
2	Underground hydrogen storage is an undesirable technology in the Netherlands	Social	-2
Most Characteristic			
8	Hydrogen needs to become the primary means of renewable energy storage.	Technical	5
27	Europe must become the world leader in electrolyzer technology.	Political	4
5	Social acceptance is one of the most critical barriers for success of hydrogen storage.	Social	4
21	A higher fossil fuel tax for the energy intensive industry would be a strong incentive for these industrial players to adopt hydrogen technologies.	Political/ economic	3
26	The EU should demonstrate more interest in green hydrogen energy storage.	Political	3
9	The considerable energy losses of conversion processes will limit the use of hydrogen.	Technical	3
Most Uncharacteristic			
35	The Netherlands should become a major hydrogen import and trade hub because of its many strategic advantages, such as its existing infrastructure and underground hydrogen storage potential.	Economic	-3
18	Based on its current leadership position in gray hydrogen production, the Netherlands should aim to become one of the biggest green hydrogen producers in Europe.	Economic	-3
4	Public ownership of large-scale hydrogen storage is not necessary for future market acceptance of green hydrogen.	Social	-3

31	The future use of hydrogen is more dangerous than the use of fossil fuels.	Safety	-4
16	Green hydrogen storage technologies should only be developed if there is an economically viable business case.	Economic	-4
34	There will be better - cheaper, and easier - methods of energy storage than green hydrogen.	Technical	-5
Quite Characteristic			
7	Hydrogen will play a critical role in further integrating the energy systems of Northwest European countries.	Technical	2
20	Incumbent energy companies like Shell and BP stand to gain most from the move towards hydrogen.	Economic	2
13	Situations of "excess renewable energy" will not occur frequently enough to justify large investments in intermittent electrolysis.	Technical	2
15	Domestic green hydrogen production will have a marginal effect on the Dutch economy.	Economic	2
3	Climate change concerns me.	Social	1
17	Because of the speed of climate change, we do not have the luxury of waiting for hydrogen technologies to become cost competitive.	Economic	1
24	The purchase of green hydrogen energy storage technologies should be stimulated by a tax break.	Political/ economic	1
22	We should turn the Netherlands into a pioneering country when it comes to hydrogen energy storage technologies.	Political/ economic	1
30	To encourage the development of hydrogen storage technologies, we need dynamic and open regulations that allow for cooperation rather than competition.	Political	1
Quite Uncharacteristic			
14	By 2030, green hydrogen will be commercially competitive with fossil fuel-based forms of hydrogen.	Economic	-1
1	Universal technology standards are not necessary for the development of hydrogen energy storage.	Technical	-1
11	Hydrogen will be especially important in the energy sector.	Technical	-1
23	The government should intervene as little as possible in the currently developing hydrogen market.	Political	-1
33	Innovations in electrical storage could make green hydrogen redundant.	Technical	-1
19	Cost efficiency of hydrogen technologies can only be marginally improved via innovation.	Economic	-2
2	Underground hydrogen storage is an undesirable technology in the Netherlands	Social	-2
10	A sustainable future can be accomplished without hydrogen technologies for energy conversion and storage.	Technical	-2
29	We need more clear policies and regulations on the possibilities of hydrogen conversion and system integration.	Political	-2

5. Appendix – Invitation Email Format

Dear …,

I hereby invite you to participate in my thesis research to complete my master's degree.

It concerns giving your opinion on the use of hydrogen as an energy storage to offset seasonal effects of renewable energy.

My name is Marco van Wijk and I am a master student of Management of Technology at TU Delft. I am writing my thesis research on this topic because of a genuine interest in the challenges and opportunities this technology offers.

Some more background information about the technology will give insight into what exactly you are expressing your opinion about. The focus of this research is on hydrogen as an energy storage, produced by electrolysis powered by solar and wind energy and stored for later conversion back to electricity. In this way, seasonal fluctuations inherent in power generation using solar and wind energy can be accommodated. The purpose of the survey is to specifically find out how respondents view hydrogen as seasonal storage in the future energy mix.

Expressing your opinion is done via the website below:

https://app.qmethodsoftware.com/study/10336

Your personal participation code (to be filled in on the website): CODE

Your personal information (email address, name and position) will only be used for purposes within this study. Your email address and name will be permanently deleted upon completion of this study, so your response will be anonymous.

If you have any questions, you can always contact us personally by mail or phone (06-12345678).

Thank you in advance for your participation,

Kind regards,

Marco van Wijk

6. Appendix – Condition of Instructions

Consent form:

You are cordially invited to participate in this research entitled "Green Hydrogen Energy Storage Sociotechnical Imaginaries". This research is conducted by me, Marco van Wijk, MSc Management of Technology student at the Faculty of Technology, Governance and Management at TU Delft. Currently, I am completing my master's degree by writing a master's thesis.

The purpose of this research is to find desired futures of green hydrogen as energy storage. The estimated time to participate in this research is about 15 minutes. You are free to contact me at the email address and phone number below to discuss the survey or ask questions.

Risks to respondents are considered minimal. There are no costs or benefits associated with your participation.

Email addresses will be kept during this study for approach to respondents only. Only I and my supervisor will have access to this data. This information will be removed from the final dataset.

All reasonable measures have been taken to protect your identity and responses. The questions in this survey do not ask you to provide personally identifiable information and IP addresses are not collected.

Your participation in this survey is voluntary. You may decline to answer any question and you have the right to withdraw your participation at any time. If you wish to withdraw from the study or if you have any questions, please contact me using my contact information: +31612345678, marcovwijk@hotmail.com.

By participating in this study, you consent that your email address will be stored for the duration of this study for the purpose of contacting you. As mentioned above, your contact information will be permanently deleted when the thesis is completed.

Before pre-sorting:

The first step of this survey involves pre-sorting 35 statements. Please indicate which statements you roughly "agree" or "disagree" with. To do so, click on the thumbs up or thumbs down. Do you not 'agree' or 'disagree' with the statement? Then click on the question mark to indicate that you are 'neutral'. Then click on 'Continue'.

Before final sorting:

Now the final step of the survey begins: the final sorting of the 35 statements. Please answer to what extent you agree or disagree with the following statements on a scale of -5 to +5. -5 refers to 'relatively disagree' and +5 refers to 'relatively agree'. You can easily drag the statements to the box with the corresponding answer. Please note that you can only place a selective number of statements on both extremes - relatively agree (disagree) - (see illustration as example). For example, you may have to place a statement on the side "relatively disagree" even though you agree with the statement. Therefore, consider the statements relative to each other and indicate which statements you relatively most (disagree) with for this ranking.