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BSc Thesis Human Geography and Planning

From technology to Implementation: The role of Hydrogen in the Energy Transition

Author:
Jasper van Wijk *(s4099710)*

Supervisor:
M. Abassiharofteh

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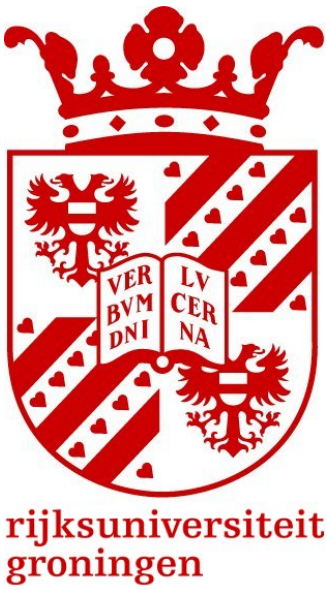

Abstract

Research has shown that in recent times hydrogen technologies have become more feasible and profitable, this should have resulted in rapid implementation of hydrogen technologies as the world tries to move away from fossil fuels. Data shows that this has not happened. The aim of this research is to gain a better understanding of what factors inhibit a successful implementation of hydrogen. To better understand why a successful outroll of hydrogen has not yet happened and how we will be able to improve the rate of implementation, the following research question is posed: 'How can green hydrogen successfully be implemented in the province of Groningen?'.

A literature review has produced the three aspects of technology, market and policy. These aspects are the main focus points of the data gathering and results for this research. Several semi-structured interviews with key stakeholders in the hydrogen sector were held in order to gain a better understanding of the situation from various viewpoints. Then the interviews were transcribed and analyzed with a thematic analysis. These interviews showed a recurring theme of too much uncertainty in the implementation of hydrogen technologies which disincentivized larger investments. The uncertainty is a structural problem that arises from the volatility of production costs in combination with increasing wait times and complexity for permits and other paperwork. To combat this, this paper encourages policy makers to streamline the paperwork that is needed for innovation while also cultivating a grass-roots bottom-up approach by assisting innovations from all levels of implementation with fair subsidies. Further research is needed to gain a better understanding of how such an approach can be realized, as this study has found that this is an area that is extremely complicated with lots of different interpretations and biases.

Contents

1 Introduction

1.1 Background

As the Netherlands has set its sights on transitioning away from fossil fuels, massive overhauls will have to be done to the current energy systems to satisfy these goals. One of these massive overhauls is the switch from natural gas to hydrogen, as hydrogen can be created from green energy resulting in a clean fuel. Hydrogen in combination with electricity will be the main pillars that support the energy system in the future (Mignone et al. 2024) [10] and as such the planning for the future of the energy systems is relying on the implementation of these carriers which makes this subject socially relevant.

But the rollout of these carriers is not going as intended, as currently in the Netherlands massive amounts of capital are needed to improve the existing electrical infrastructure as demand for electricity keeps growing (Rijksoverheid, 2024) [15]. More and more government agencies are encouraging the electrification of households and transport but as the grid in the Netherlands is reaching its breaking point (NOS, 2023) [12] these ambitions may not be feasible. In one case (NOS, 2023) [11] a new apartment complex was fitted with electric heating systems. However, these were unable to be connected completely due to a lack of grid space. The solution to this was to retrofit this entire apartment complex with a new set of natural gas powered heating systems.

The story for the rollout of hydrogen is much the same, it is expected to fill a major role in the long term energy system but current goals set by the government are optimistic in comparison to the actual data, as more and more projects are delayed (S&P Global 2024) [17] or canceled. An example of this is the hydrogen plant that Uniper is building in Rotterdam, which has been delayed for 2 more years and they're giving back the subsidies from the EU since they're unable to produce on schedule due to too many uncertainties and high grid fees. This contradicts the literature (Schrotenboer et al. 2022) [18]), which paints quite a good picture for the future of hydrogen technologies. This makes looking into this subject scientifically relevant as at a glance the theory contradicts reality.

This sparked my interest in wanting to find out what was going wrong with the implementation. To this end this research is going to be looking at the energy transition and the implementation of hydrogen technologies within the energy system with its role as an energy dense low-carbon fuel source

1.2 Research Problem

The successful implementation of green hydrogen in Groningen requires navigating various complicated challenges, from the technological implications to financial feasibility. This research aims to look into this by way of this main research question:

How can green hydrogen successfully be implemented in the province of Groningen?

By answering this main research question this study aims to illustrate the possibilities and barriers to the implementation of hydrogen technologies in Groningen. But the research question raises the question of what implementation actually means. In the context of this research a successful implementation of green hydrogen would be achieved when hydrogen is widely adopted in many different sectors, and used in situations where electrification is not an option. As an example in a country or region with a successful implementation of hydrogen, industries that require natural gas would all be able to completely switch over to hydrogen. On top of this hydrogen powered vehicles could be competitive with regular electric vehicles.

1.3 Sub Questions

To gain a better grasp of how exactly the main research question can be answered sub questions are created to help in this endeavor. To better understand how a successful implementation can be realized it is important to know what actually leads to a successful implementation, thus follows the sub question;

What are the factors triggering successful implementation?

Realizing what triggers a successful implementation means that it is also important to realize what can cause the opposite, in this case what problems can arise thus follows the sub question;

What are the problems regarding successful implementation?

As the government has the capabilities to restrict and enable aspects of the implementation of hydrogen it is imperative to understand its role in the wider scheme, thus follows the sub question;

What is the role of the government in implementation?

Since a technology will only be widely adopted if it is financially feasible, it will be important to understand the role of the market. Thus follows the sub question;

What is the role of the market in implementation?

As the technology behind the creation of green hydrogen is constantly evolving, understanding its role in the implementation is important. Thus follows the sub question;

How has technology impacted the implementation?

With these subquestions we will be able to answer the main research question and gain further insight into the hydrogen sector.

2 Theoretical Framework

Currently the entire world is moving away from fossil fuels to reduce emissions, this shift is called the energy transition. In this transition towards various green energy sources hydrogen is emerging as a key player. French (2024) [4] states:

'*There is a growing realization that hydrogen has a vital role to play, particularly to decarbonise sectors and applications that are otherwise extremely difficult to abate, such as industrial processes, heavy duty freight movement, dispatchable power generation and heating applications.*'

Although hydrogen's role in the future of the energy transition is undeniable, the energy transition faces similar challenges and opportunities all across the board. As the costs of renewable energy sources have decreased dramatically (IRENA 2022) [7] installation of them has increased in tandem. But even as the amount of renewable energy being generated increases it is not always enough to satisfy the need. This in combination with infrastructural issues shows that even though the applicability of renewable energy sources has increased dramatically, big problems still remain.

The subject of hydrogen intertwines nicely in the theme of ''small steps toward tackling grand challenges" as the literature shows that the energy transition is a wicked problem. Bours et al. (2022) [2] talks about how a small bottom up approach can be used to great effect to combat these wicked problems, which is one of the steps that is currently taking place in the province of Groningen as Schrotenboer et al. (2022) [18] calls it ''Europe's first hydrogen valley". This bottom up situation makes Groningen an interesting case to look at in this paper as this supposed hydrogen valley is also dealing with various implementation problems.

The research will focus on three aspects that are major make or break factors in the outroll of hydrogen. These aspects are; the role of technology, the role of the market and the role of policy.
These three aspects are derived from the work of Hasankhani et al. (2024) [5]. Hasankhani et al. (2024) [5] focuses on five core domains that were derived from stakeholder dialogue. These five core domains are technical, infrastructural, socioeconomic, environmental and institutional. For this research these five core domains have been analysed and consolidated to three more broader ones as this allows this research to be more cohesive and less fragmented while also staying within reasonable scope. Through the lens of theory we will be looking at these three aspects and what makes them so important and relevant to this research.

2.1 Technology

Hydrogen is bound to play a big part in the energy transition (Reigstad et al. 2022) [14]. It is an energy dense fuel that can be fabricated with natural gas resulting in the so-called gray or blue hydrogen, or electricity that can be generated from renewable sources resulting in green hydrogen, which is what this research is going to be focusing on.

But the implementation of green hydrogen is not as easy as it seems, as Giovanni et al. (2023) [8] notes that even though hydrogen technologies have matured a lot, large scale implementations are untouched ground and are prone to technological and infrastructural barriers. To kickstart a hydrogen based energy system Giovanni et al. (2023) [8] suggest that blue hydrogen is able to give a baseline of hydrogen that should pave the way for green hydrogen allowing it to develop the demand needed to reduce production costs. Understanding these technological barriers is key to gaining a better perspective on the implementation of the technology in a wider context, which is why it is a key factor in this research.

2.2 Market

Green hydrogen is an excellent way to harness an excess of energy in an energy grid, for example by having the capabilities to turn excess energy into green hydrogen wind turbines at sea will become more profitable. Schrotenboer et al. (2022) [18] even calculated that this flexibility can result in an increase in revenue of 126.000 euro per year per turbine.

At the same time an excess of energy is not something that we can always count on, especially considering the volatile nature of renewable outputs such as wind or sun. In this regard Ajanovic et al. (2024) [1] notes that the implementation of wide scale green hydrogen in Europe might not be plausible in the short term as current renewable electricity generation is insufficient when related to what green hydrogen would need for a widespread adoption.

And to add onto this Hasankhani et al. (2024) [5] found during their research that a large consensus of their interviewees noted the big financial challenges posed by high initial costs and scalability issues. Illustrating that the current subsidies might not be enough to attract investment towards this industry. This dichotomy illustrates the need to further look into the role of the market on the implementation of hydrogen which is why it is one of the focuses of this research.

2.3 Policy

A major transition such as the transition to hydrogen is something that has to be supported by policy otherwise it will not be able to succeed. Hisschemöller et al. (2011) [6] has found that the energy transition would benefit from adapting its policies to be more pluralistic as according to them this would allow for more competition and investments into the market which is something that would promote the implementation of hydrogen. At the same time though they note that these changes are a huge challenge for the Netherlands. This shows that policy has a major role to play in attracting competition and newcomers into the market of hydrogen which is essential to reaching the goal of a hydrogen supported energy system.

The difficulty lies in the multidisciplinary nature and wide variety of stakeholders in the energy sector, Hisschemöller et al. (2011) [6] states: ''The dialogue reveals that stakeholders are strongly divided with respect to small-scale domestic as well as the concept of a flexible natural gas infrastructure. We find a conflict between knowledge claims that either support or challenge the status quo." On top of this the research also found that this conflict is not something that is resolved with more research or interaction between stakeholders, as this conflict requires change from the institutional side to actually be resolved.

The literature paints a bright future for hydrogen technologies, by some studies already profitable and by some studies an inevitability but current plans are only planning for green hydrogen to be a few percentage points of the energy supply at best. (NWP 2022) [3]

There is a literature gap in the field of applying hydrogen to the current energy transition, there is research being done (Schrotenboer et al [18]. & Reigstad et al [14].) on the possibilities of applying hydrogen to different parts of the energy transition such as transport or industry but for the most part the link towards actual practice/implementation is lacking.

For this reason my research question is geared towards the practical implementation of hydrogen in the energy transition. Specifically, my research question aims to investigate the barriers hindering the widespread adoption of hydrogen technologies across various sectors and to propose strategies for overcoming these obstacles.

2.4 Conceptual Model

This conceptual model visualizes the three factors found in the theoretical framework and by focusing on these 3 factors during research it is possible to gather data with which we will be able to answer the main research question. The three factors are supported by the concrete examples given in the theoretical framework giving them more tangibility.

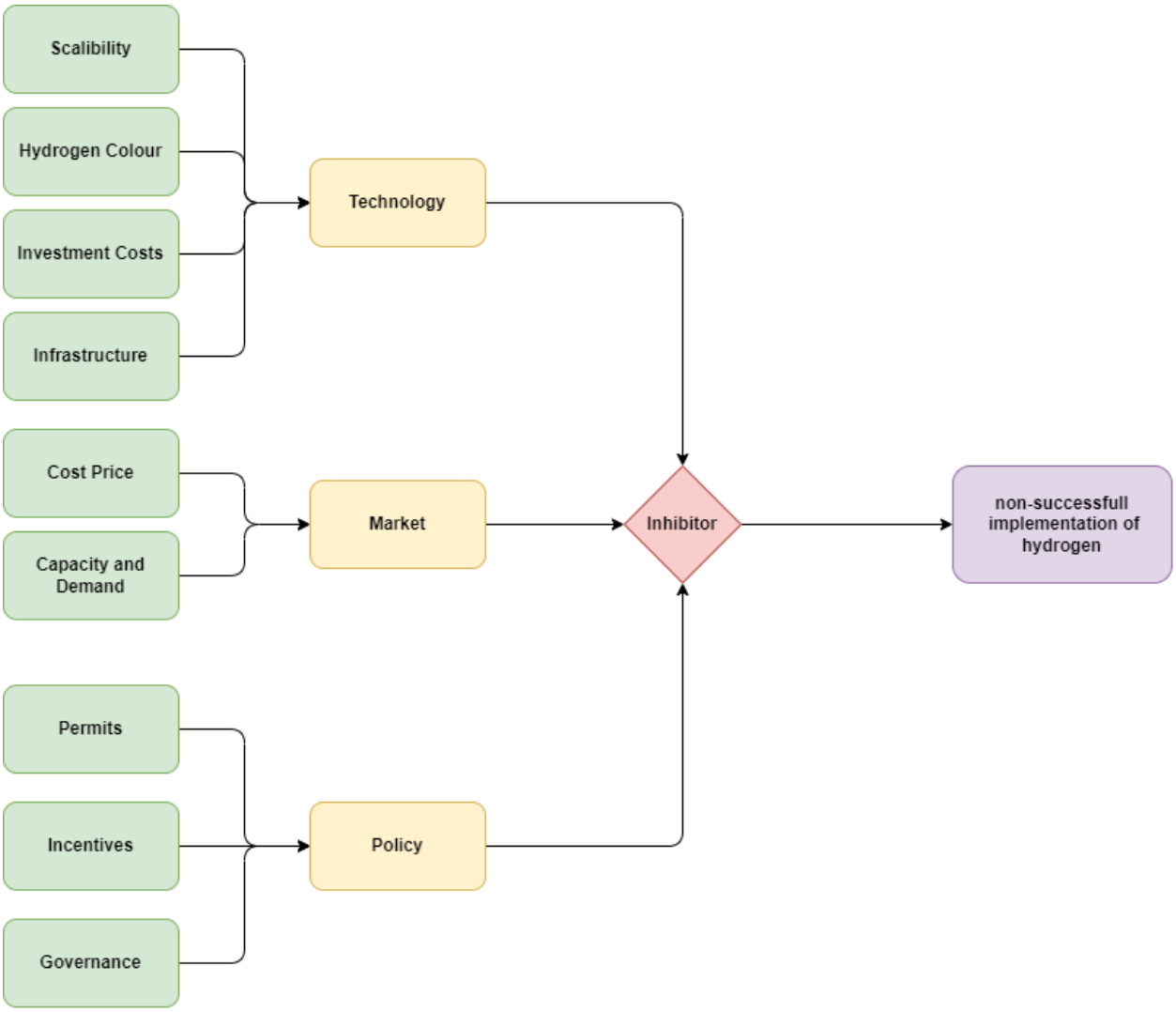

Figure 1: Conceptual Model. Source: Author

This conceptual model shows what factors inhibit the implementation of hydrogen technologies. This also helps in finding relevant participants for the interviews, as the interviewees are expected to provide input on these 3 factors in relation to the implementation of hydrogen.

2.5 Expectations

In line with qualitative research, that is fuzzy, expectations were designed. As the literature has shown that green hydrogen has a bright future with great applications in regard to the energy transition, it is expected that in the future it will be playing a large part in the energy infrastructure which results in the following expectation:

Groningen will lean on green hydrogen as a fundamental part of their future energy infrastructure.

The literature has shown that the technologies behind hydrogen have matured rapidly, and that the process of electrolysis is not the bottleneck in its implementation. Thus we form the following expectation for this research:

The technology behind hydrogen has reached maturity.

The literature notes that for a successful wide implementation of hydrogen, policy needs to go through major changes as current policy is inadequate on many fronts. Issues with attracting investments and competition due to convoluted bureaucracy is one of these inadequacies. To this end the following expectation is formed:

Bureaucracy will be a make or break point for hydrogen integration.

As hydrogen is currently quite expensive we expect the outroll of more hydrogen production capacity to reduce these prices, allowing for more sectors to implement hydrogen. This results in the following expectation:

The price of hydrogen will sharply decline in the coming years.

By addressing these expectations during the data collection process this research aims to gain a better understanding of the situation in the hydrogen sector.

3 Methodology

As the research question wants to find out what barriers there are to the implementation of hydrogen technologies, qualitative interviews will be held as these will allow this research to have in-depth conversations with stakeholders and get a better idea of what is going on with the implementation of hydrogen. Contact will be made with the various stakeholders through email and phone calls, this contact information will be acquired through snowball-sampling in combination with convenience sampling. Because in a sector such as this most interviewees will be well connected to other interesting interviewees, which will allow this research to quickly gather relevant participants for the interviews. My approach resembles the approach of the paper by Xiao et al. (2023) [19] as in that paper it was found that a snowball-sampling strategy in combination with convenience sampling was able to reach a large number of people working in the same sector.

The interviews will be semi-structured because there is a focus on discussing the central theme of hydrogen implementation with the various stakeholders but at the same time it is imperative to give interviewees the room to bring up different ideas and views during the interview as these can give valuable insight into their opinions on the matter. The aim is to interview various people in the industrial sector, regional government and energy sector as these are all relevant stakeholders within the hydrogen sector which makes their input valuable for this research.

It will be important to understand the positionality of each interviewee and assess their role in the industry beforehand. By gathering this information before the interviews it will be possible to take this into account and understand their possible biases and take these into account when analyzing the data. As various interviewees might have a bias towards implementation since they have different end goals we will be applying techniques posed by Patton (1990) [13] such as remaining neutral during the interview.

3.1 The Interviews

To guide the interviews and make sure applicable data is gathered from all interviewees an interview guide was used, this interview guide has been added as an appendix. (Appendix B) The questions in the interview guide are general and not directly applicable to all interviewees and their context, to this end slight adjustments are made to these questions before the actual interview to make sure that the desired speciality of an interviewee can be shown.

The aim is to interview various people identified through the conceptual model (Figure 1). The conceptual model allows this research to focus on gaining participants that have knowledge surrounding the 3 identified factors of Technology, Market and Policy. As the interviewees will be representative stakeholders within the hydrogen sector their input will be a reflection of the broad landscape that surrounds the hydrogen industry.

During the interviews a notepad will be used to both, note down important things the interviewee mentions and show the interviewee that he is giving useful data and his input is being valued. The interviews will be held between 15-3-2024 and 17-5-2024, these self-imposed deadlines are to ensure that there is adequate time left for the gathered data to be analyzed correctly. The interviews will naturally vary in duration but the aim is to have every interview be between 30-60 minutes in length. As the interviews will be held with stakeholders within the region it should be possible to have them all in the place of choosing for the interviewee. The expectation is that the interviewer will have to travel to the various stakeholders and conduct the interviews on-site as this is a natural location for the interviews and shows interest from the researcher's end.

3.2 Analyzing the Data

To actually be able to draw useful conclusions from the data collected it will be imperative to analyze this data. For qualitative methods we can rely on various data analysis methods.To analyze this primary data a thematic analysis will be used, the approach used resembles the approach used by Lee et al. (2024) [9] as

in that study the thematic analysis allowed them to identify key barriers and facilitators for their research which is also the goal of this research.

After familiarizing myself with the data through transcribing and re-reading the interviews, codes will be created for the transcript of the interviews and with these codes certain themes can become visible within the conducted interviews, after organizing these themes and meanings we will be able to draw meaningful conclusions from the interviews which will then be used to answer the research question. As an example we might notice a positive viewpoint from various stakeholders towards certain developments, this can then be interpreted into a conclusion of ''Generally the interviewees have a positive outlook towards more government subsidies for hydrogen implementation"

The exact steps that will be taken for the data analysis are represented in the following schematic;

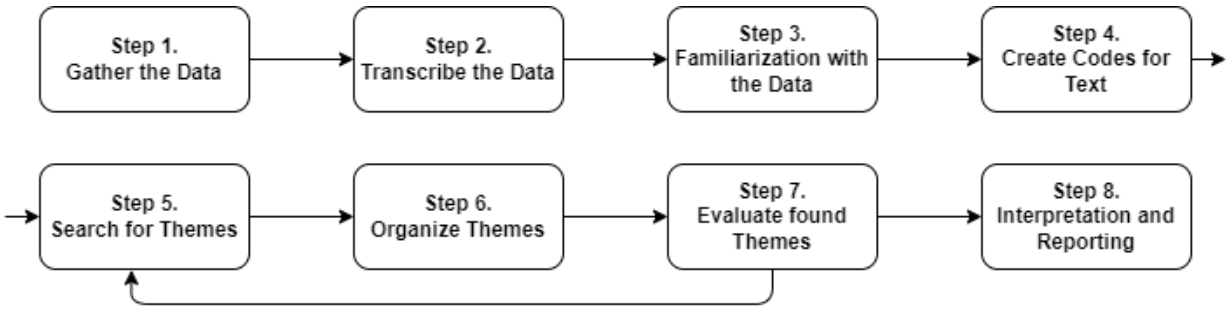

Figure 2: Data Analysis Schematic. Source: Author

3.3 Ethical Issues and Data Protection

Before any interview starts the first thing an interviewee will do is read and accept or decline the consent form. This consent form will state what the data will be used for, how long it will be stored, where it will be stored and that they are able to rescind consent at any moment if they wish to do so. The consent form used for the interviews has been added as an appendix. (Appendix A)

Since the interview will be recorded it is important to properly protect this data. This will be done by transferring the recordings to the encrypted RUG server and my personal encrypted storage, while also deleting the recording from my phone afterwards. After this has been done all analysis and transcription will be done in a safe environment with applications that have been screened by the RUG to prevent data breaches. In the case that a data breach does happen the interviewee(‘s) in question will be notified of this and contact with my supervisor will be established to see what has been lost and whether any further action is required.

3.4 Quality of the Data

Despite the best efforts of this study establishing contact with certain institutions and people has proven to be quite difficult, certain areas of the hydrogen sector are thus underrepresented in the data which might result in skewed conclusions.

Apart from the difficulties contacting certain actors the data collection was quite successful with 8 successful interviews taking place. Of these 8 interviews 4 were done in place and 4 were done online. The goal was to have all interviews be in place which would allow for more in-depth data gathering but because some interviewees had extremely tight schedules in person interviews were not feasible. The effects this had on the data collection were small but noticeable as it became clear that interviews that were held in person gave more interesting responses and went more in depth for their situation. Table 1 gives a short description of the interviewees and their expertise;

Interviewee	**Sector**	**Expertise**
A	Energy Generation	Subsidies and Implementation
B	Startup and Innovation	Collaboration and Technology
C	Infrastructure	Role of Distributor and Policy
D	Industry	Policy and Market
E	Infrastructure	Policy and Collaboration
F	Governmental	Policy and Subsidies
G	Governmental	Politics and Subsidies
H	Industry	Policy and Market

Table 1: Interviewee Sectors and Expertise. Source: Author

4 Results and Analysis

4.1 Conceptual Model

This research was successful in gathering interviewees, resulting in 8 interviews being held and various viewpoints on the subject being captured. To maintain anonymity of the participants they will henceforth be referred to as interviewee A to H, and genderless pronouns will be used in tandem with these names. The data gathered through these interviews has been analyzed according to the data analysis scheme found in figure 2. This analysis has produced five main themes, these themes are as follows:

1. Technology has not Matured Fully
2. Market is Unable to handle Uncertainty
3. Different role of Subsidies
4. Stronger role of Government
5. Clear Goal, Unclear Path

These themes have then been linked to the three factors found in both figure 1 and the data collection process that can be seen in appendix B. The result of this is visualized in figure 3.

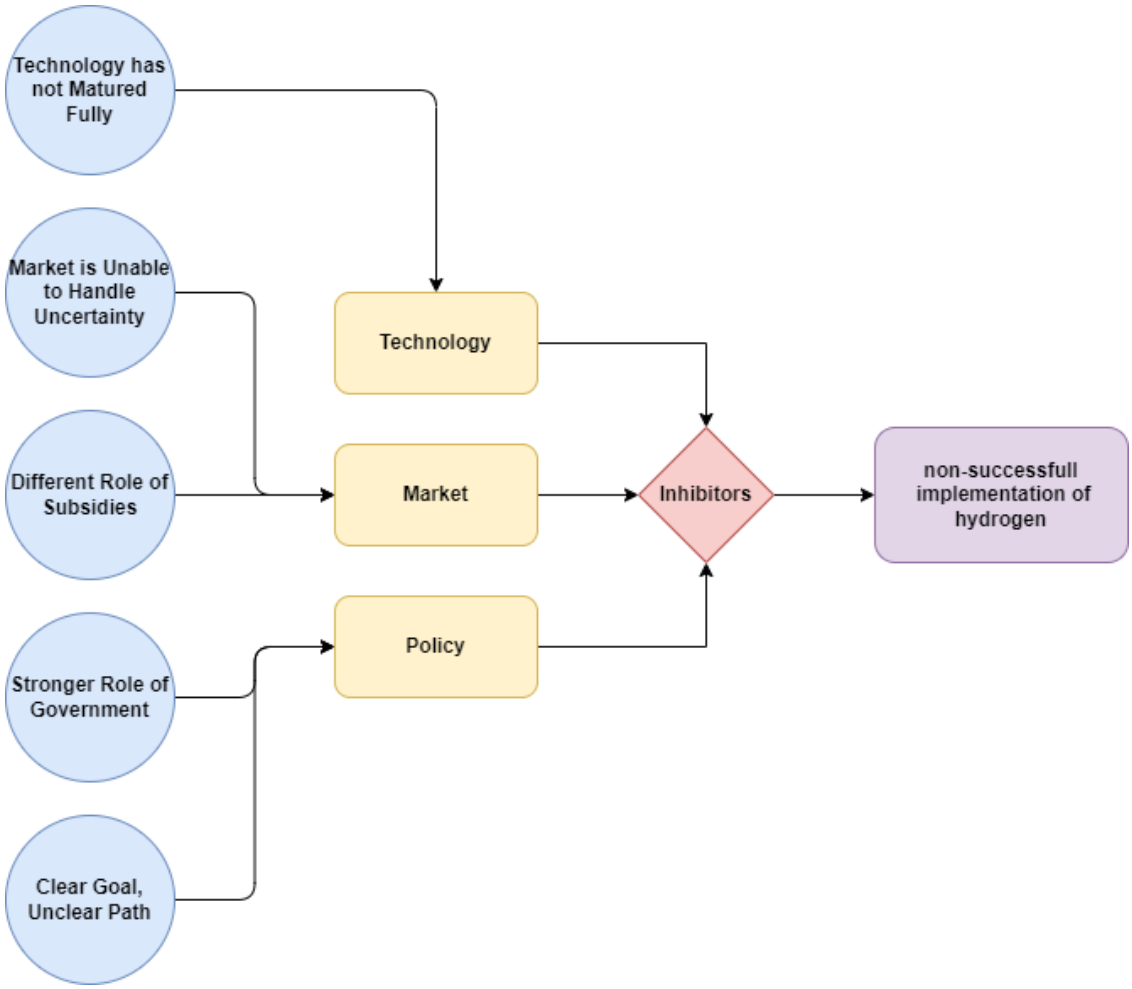

Figure 3: Themes in combination with Conceptual Model. Source: Author

The structure of the results and analysis will follow the structure of figure 3 resulting in the following chapters being divided into the three factors of; Technology, Market and Policy. For each of these factors the themes that were found during the analysis will be discussed and related to them in conjunction with the literature.

4.2 Technology

During the interviews with the people that are directly involved in the implementation of electrolysis it was noted early on that there was a recurring theme that the technology is far from maturity. An example was given that the implementation of a combustion engine was straightforward since we have so much experience with the technology that the uncertainties in its use are very small. In comparison the large-scale usage of using electrolysis to extract hydrogen is largely unexplored territory which comes with its own set of problems that all involved parties are currently trying to work out.

According to interviewee C:

'These projects aren't technically stable. So the thing doesn't pump out hydrogen for 7,8,160 hours without issues. And we have to work up to electrolysis for a gigawatt, and if you are unable to get 10 megawatt stable and you want to work up to a factor of 100. There are some technological challenges ahead.'

The found theme of the un-matured technology is corroborated in the paper by Giovanni et al. (2023) [8] which also noted that implementation would be difficult due to the problems faced by implementing a non-matured technology. Both the paper by Giovanni et al. (2023) [8] and the analysis agree that in the early stages of the adoption of hydrogen into the Dutch energy system it might be a good idea to lean more on blue hydrogen. This will be able to provide a more stable baseline that is able to support the start of a hydrogen based economy, as currently the large uncertainty that comes with such an unstable technology is hindering widespread adoption.

Another interesting thing was that the interviewees from sectors where hydrogen would actually be implemented all showed that there was a lot of will towards reaching the climate goals. It was noted that the companies themselves want to reach these goals in any way that they could. But they were frustrated because even though for their applications introducing hydrogen was technically speaking very doable, it would take a really long time before they would be able to receive any due to the current state of the implementation of hydrogen.

Parties that use a large amount of natural gas and thus in the future would need a large amount of hydrogen are mostly dependent on the outroll of the Hydrogen Backbone, which is the big hydrogen infrastructure project of the Gasunie. But for some parties their connection to the Backbone could take up to 8 or 9 years which means that they are basically unable to meet the climate goal set by the Netherlands of halving emissions in 2030.

4.3 Market

The fact that the technology is not yet completely reliable logically has consequences for the business case of green hydrogen. What became clear early on during the interviews was that the business case of hydrogen was largely responsible for the slow rollout of green hydrogen. Interviewee A commented this when prompted about the production of hydrogen:

'At this moment there is no business case for hydrogen production. So the parties who are looking at doing this, are doing this with an eye for the long term.'

The parties that are supposed to be creating the hydrogen plants that provide the green hydrogen are not non-profits, for them to be able to make deep investments into this technology there has to be some kind of incentive. Without outside support this incentive just isn't there, which results in a systematic delay in

implementation. To give this incentive the Dutch government has provided (Rijksoverheid 2024) [16] several parties with subsidies for their larger electrolyzer projects, but according to the analysis the current market is unable to handle the uncertainties posed even with these subsidies. To this end they propose that the Dutch government should give operational subsidies on the production of hydrogen. Interviewee G when prompted about subsidies had this to say:

'But we have said that, there has to be an operational subsidy on the production of hydrogen. Otherwise it's just not attractive, then those companies will just stay on natural gas or gray hydrogen if they specifically need hydrogen.'

This operational subsidy would be able to stimulate projects of all sizes since the subsidy is granted on the base of production which would in turn greatly stimulate the thus far lackluster implementation of green hydrogen. What form this operational subsidy would take on is beyond the scope of this study

Even if suddenly green hydrogen production is able to catch on and production ramps up, the amount of green energy that is required for this will become the next bottleneck. As Ajanovic et al. (2024) [1] notes that implementation is currently not possible due to a lack of green energy. The lack of green energy is a study subject in and of itself that deals with the same types of issues as the implementation of green hydrogen.

On top of this the inability for the technology to be reliable explains the apparent dichotomy that was found between different research that was done into the financial feasibility of green hydrogen. Schrotenboer et al. (2022) [18] calculated that introducing hydrogen into renewable energy systems could improve profits by as much as 20%. But at the same time Hasankhani et al. (2024) [5] found that high initial costs and scalability issues make it difficult to attain widespread implementation. This difference is explained by the fact that a successfully operating hydrogen plant would indeed be able to generate such an increase in profit, but getting to a level where we have large scale successful hydrogen production facilities is very expensive and technically speaking extremely difficult.

4.4 Policy

A theme which came through quite clear during the analysis was that the implementation of hydrogen and the goal set by the government in relation to reducing emissions was not seen as a problem, since the analysis shows that stakeholders feel that they themselves have to play a role in the energy transition and see it as necessary when looking towards climate change.

Problems arose however when looking towards how these goals would be realized, there was a strong feeling that the government had a clear goal which it wanted to achieve but that there was no vision of how to realistically achieve them. This stems from the fact that over time the tax on carbon emissions would rise forcing those who emit carbon to pay hefty fines, at the same time many stakeholders are unable to switch to low carbon alternatives like green hydrogen resulting in them being pushed into a corner with no real way out. When the interviewer brought up the concept of the carrot and the stick interviewee D had this to say:

''It actually is a baseball bat and a whip really, it has nothing to do with the carrot"

From this reasoning came the main criticism towards Dutch policy; a goal with no reasonable way to achieve it in its intended time frame. The analysis concludes that a stronger governmental role is desired by stakeholders, an example was given that in the 1960's natural gas was introduced with strong help from the Dutch government, and the current transition to hydrogen is as large as or even bigger than the transition to natural gas. But this time the government is not taking the strong, central role that it was during the introduction of natural gas. During the analysis it became clear that a stronger role of government was desired, as stakeholders agree that the current uncertainties that come with the implementation of hydrogen is not something that the market is able to handle.

A small addendum that did not deserve its own section but still needs to be mentioned is that the analysis

has also shown that criticism towards governmental goal setting was not limited to the implementation of hydrogen. For a lot of the criticism was also expressed towards implementation goals of other green initiatives. Interviewee G had this to say when prompted about being realistic with plans:

'For example you have the goal of realizing wind parks at sea. So 21GW in 2030 and 70GW in 2050, that's complete nonsense. That's just not gonna happen, despite that it's still in all the governmental plans.'

This shows that the problems seen on the policy side with the implementation of hydrogen are not limited to it, but actually stretch over a broader theme.

5 Conclusions and Discussion

This research has shown that a better integrated approach is needed to successfully initiate the hydrogen economy that the Dutch government plans for. As currently the uncertainties that unmatured technology brings with it are unable to be handled by the market alone. To remedify this a stronger role of the government is needed, as a stronger governmental role is able to burden this uncertainty resulting in a more successful implementation of hydrogen for not only Groningen but for the entirety of the Netherlands.

Similar research such as the research done by Hasankhani et al. (2024) [5] has found that improved clarity towards all involved parties is essential, together with a responsive and flexible governance system. These results are similar to the results found in this study as the analysis shows that currently clarity on implementation is lacking. On top of this the role of governance is shown to be crucial in both studies.

With these conclusion this research adds to the academic discussion surrounding the implementation of hydrogen, as this research has shown that multiple different studies with seemingly conflicting conclusion can all still be true due to the complicated situation and outroll this sector finds itself in.
The expectations of this research have shown to be both true and false in part. One of the expectations was that the price of hydrogen would go down significantly and according to the interviewees it will, but even a drastic decrease in the price of hydrogen still would not be able to overcome the enormous price difference it has with natural gas. And while it is true that Groningen will lean on green hydrogen in the future, the unmatured state of its technology shows that this goal may well be some time away.

5.1 Limitations

One of the limitations of this study was the quantity of the data gathering. For future research a wider data gathering scope might be needed to ensure all voices in the sector are heard, sadly for this study that scope was not justifiable as the time constraint on gathering participants was already a hard constraint.

Another limitation was the quality of the analysis. This research was the first time this researcher has worked with qualitative data, so the analysis might not be a perfect representation of the data. Nonetheless the author still feels that they have produced a good analysis that is adequate for the purpose of this study.

5.2 Future Research

The subjects of the operational subsidy and the lack of green energy came forth during analysis. These subjects are very complicated and sadly out of the scope of this research, further research could be done into these subjects to gain a better understanding of why there is a lack of green energy and how this can be solved. On top of this the structure of the operational subsidy on the production of green hydrogen

5.3 Policy Implications

With this research it is hoped that the Dutch government takes a more active approach in helping the hydrogen economy start, this could be achieved by providing certainty for the production of hydrogen by establishing operational subsidies for hydrogen production. With this operating subsidy a true hydrogen market can be kick started which would result in more competition and investment into the sector, this in turn would realize the beginning of an actual hydrogen economy as the government is aiming to create.

In turn more investments into hydrogen could enable more investments into renewables in general as green hydrogen requires green energy. Creating such an energy cascade could help the Netherlands realize the ambitious climate goals that are currently, as this research has concluded, optimistic at best.

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6 Appendices

6.1 Appendix A, Consent Form

Toestemmingsformulier

Betreft: Onderzoek naar integratie van waterstoftechnologie in provincie Groningen

Hallo! Mijn naam is Jasper van Wijk en ik ben student aan de Rijksuniversiteit Groningen. Voor mijn scriptie doe ik onderzoek naar de integratie van waterstof technologieën in Groningen. In mijn onderzoek maak ik gebruik van interviews met verschillende belanghebbende partijen. Om het interview correct te kunnen analyseren is er een transcriptie nodig, waardoor het nodig is om het interview op te nemen.

De data die ik verkrijg in deze interviews zal strikt vertrouwelijk blijven en alleen ik en mijn supervisor hebben hier toegang tot. De data wordt opgeslagen op de encrypted server van de RUG en mijn eigen encrypted harddrive. Deze data wordt niet langer dan 2 maanden na afsluiting van dit project vastgehouden (Medio Juni), hierna zal het permanent verwijderd worden.

Bent u akkoord met de volgende punten:

- ☐ Ik heb de tekst hierboven gelezen en ga akkoord met deze voorwaarden
- ☐ Ik heb de mogelijkheid gekregen om vragen te stellen over dit onderzoek/interview
- ☐ Ik geef toestemming om mee te doen aan dit interview
- ☐ Ik geef toestemming voor een geluidsopname van dit interview

Optioneel:

- ☐ Ik wil een kopie van het eindresultaat van dit onderzoek
- ☐ Ik wil een kopie van de geluidsopname

Door uw handtekening te zetten gaat u akkoord met de bovengenoemde voorwaarden.

Handtekening deelnemer:_____ Datum:_____

Handtekening onderzoeker:_____ Datum:_____

U heeft na deelname altijd het recht om uw data te zien, aan te passen of compleet te verwijderen. Indien u dit recht wilt gebruiken kan u contact opnemen met mij via: j.j.van.wijk.1@student.rug.nl

6.2 Appendix B, Interview Guide

Interview Guide

- Eigen introductie
- Hoe het interview en de data gebruikt gaat worden en hoe het wordt gewaarborgt
- Toestemming om het interview op te nemen + toestemmingsformulier

Dit interview is gestructureerd door de 3 factoren die ik heb gevonden in mijn literatuuronderzoek namelijk: Technologie, Markt en Beleid.

Technologische Innovaties

- Kunt u uitleggen welke rol waterstof kan vullen in uw sector?
- Wat voor kleur waterstof gaan jullie produceren?
- Voor wat voor afnemers willen jullie gaan produceren?
- Hoe moeilijk is het om waterstof in uw context toe te passen?
    - Is het relatief duur of juist relatief makkelijk/goedkoop?
    - Hoe snel kunnen jullie dit implementeren?
- Hoe verhoudt groene waterstof zich tot andere hernieuwbare energiebronnen binnen uw context?
- Waar liggen de grootste technische uitdagingen voor jullie op het gebied van waterstof?
- Problemen met het stroomnet?
- Er wordt vaak gesproken over dat technologien zoals waterstof zich moeilijk verspreiden binnen een regio, wat merkt u hier van?
    - Is het moeilijk om bedrijven te vinden die concrete oplossingen bieden?

Markt

- Hoe lijkt het financiële plaatje van waterstof binnen uw context?
- Hoe concurreren waterstof energieprijzen met die van andere energiebronnen?
    - Op het moment weet ik dat waterstof tanken voor een auto ongeveer 30% duurder is dan fossiele brandstoffen, zal dit ook het geval zijn bij jullie?
    - Of gaat het mensen puur om de energietransitie?
- Vaak als er gesproken wordt over waterstof hoor je eigenlijk het kip/ei verhaal, niemand gaat waterstof gebruiken als er geen infrastructuur voor is maar er komt geen infrastructuur als niemand waterstof gebruikt. Hoe ziet u dit ?
- De afgelopen jaren hebben geopolitieke gebeurtenissen zoals het sluiten van de Nord Stream en dergelijk grote impact gehad op de prijzen van fossiele brandstoffen, wat voor impact hebben deze hoge prijzen en grote fluctuaties gehad op uw visie?

Wet en regelgeving

- Wat is uw mening over het huidige beleid voor waterstof implementatie?
    - Zijn jullie tegen dingen aangelopen?
- Wat is volgens u de impact van het beleid van nu?
- Waar ziet u kansen voor beleids verbetering?
- Hoe zouden jullie de wet en regelgeving veranderen?
    - Hoe zien jullie dit uitgewerkt?
    - Op welke termijn?
    - Wie is hier bij betrokken?
- Sinds 1 januari dit jaar hebben we in Nederland een nieuwe omgevingswet, deze wet hoort alles makkelijker en simpeler te maken. Wat merken jullie hiervan?
- Ook qua regering in Nederland is er nu veel onzekerheid, we hebben gezien dat we de afgelopen verkiezingen een stuk naar rechts zijn gegaan op het politieke spectrum en het is natuurlijk maar de vraag wat er gaat gebeuren met bepaalde regelingen en subsidies als er partijen aan de macht komen die klimaat en de energietransitie toch even iets anders zien wat zorgt voor een hoop onzekerheid op meerdere vlakken, waar zien jullie dit eigenlijk terug?

Afsluitende Punten

- Zijn er belangrijke dingen die ik volgens u niet genoemd heb tijdens dit interview?
- Zijn er specifieke mensen of organisaties die volgens u interessant zouden zijn om te interviewen voor mijn scriptie?
- Dank voor deelname

6.3 Appendix C, Data Management Plan

1. General	From technology to implementation: The role of hydrogen in the energy transition
1.1 Name & title of thesis	Jasper van Wijk S4099710
1.2 *(if applicable)* Organisation. Provide details on the organisation where the research takes place if this applies (in case of an internship).	Rijksuniversiteit Groningen, Faculty of Spatial Sciences

2 Data collection – the creation of data	
2.1. Which data formats or which sources are used in the project? For example: - theoretical research, using literature and publicly available resources - Survey Data - Field Data - Interviews	Provide a short description of the sources/data that you are going to use. I am going to conduct interviews with various stakeholders within the sector, the data is going to consist of audio files and possibly transcripts of these audio files. There is a possibility of quantitative data being used which will be data sets related to the energy sector
2.2 Methods of data collection What method(s) do you use for the collection of data. (Tick all boxes that apply)	☒ Structured individual interviews ☒ Semi-structured individual interviews ☐ Structured group interviews ☐ Semi-structured group interviews ☐ Observations ☐ Survey(s) ☐ Experiment(s) in real life (interventions) ☒ Secondary analyses on existing data sets (if so: please also fill in 2.3) ☒ Public sources (e.g. University Library) ☐ Other (explain):
2.3. (If applicable): if you have selected 'Secondary analyses on existing datasets': who provides the data set?	☐ Data is supplied by the University of Groningen. ☒ Data have been supplied by an external party. (Please mention the party here). CBS, maybe data from stakeholders

3 Storage, Sharing and Archiving	
3.1 Where will the (raw) data be stored *during* research? If you want to store research data, it is good practice to ask yourself some questions: • How big is my dataset at the end of my research?	☐ X-drive of UG network ☐ Y-drive of UG network ☐ (Shared) UG Google Drive ☐ Unishare ☒ Personal laptop or computer ☐ External devices (USB, harddisk, NAS)

• Do I want to collaborate on the data? • How confidential is my data? • How do I make sure I do not lose my data? Need more information? Take a look at the site of the Digital Competence Centre (DCC)) Feel free to contact the DCC for questions: dcc@rug.nl	☐ Other (explain):
3.2 Where are you planning to store / archive the data after you have finished your research? Please explain where and for how long. Also explain who has access to these data NB do not use a personal UG network or google drive for archiving data!	☒ X-drive of UG network ☐ Y-drive of UG network ☐ (Shared) UG Google Drive ☐ Unishare ☐ In a repository (i.e. DataverseNL) ☐ Other (explain): The retention period will be [2] Months
3.3 Sharing of data With whom will you be sharing data during your research?	☒ University of Groningen ☐ Universities or other parties in Europe ☐ Universities or other parties outside Europe ☐ I will not be sharing data

4. Personal data	
4.1 Collecting personal data Will you be collecting personal data? If you are conducting research with personal data you have to comply to the General Data Privacy Regulation (GDPR). Please fill in the questions found in the appendix 3 on personal data.	Yes/no No, I will most likely not be collectiong personal data If this changes I will also change this document
If the answer to 4.1 is 'no', please skip the section below and proceed to section 5	
4.2 What kinds of categories of people are involved? Have you determined whether these people are vulnerable in any way (see FAQ)? If so, your supervisor will need to agree.	My research project involves: ☐ Adults (not vulnerable) ≥ 18 years ☐ Minors < 16 years ☐ Minors < 18 years ☐ Patients ☐ (other) vulnerable persons, namely (please provide an explanation what makes these persons vulnerable) (Please give a short description of the categories of research participants that you are going to involve in your research.)
4.3 Will participants be enlisted in the project without their knowledge and/or consent? (E.g., via covert observation of people in public	Yes/no No, all participants will consent before being interviewed If yes, please explain if, when and how you will

places, or by using social media data.)	inform the participants about the study.
4.4 Categories of personal data that are processed. Mention all types of data that you systematically collect and store. If you use particular kinds of software, then check what the software is doing as well. Of course, always ask yourself if you need all categories of data for your project.	☐ Name and address details ☐ Telephone number ☐ Email address ☐ Nationality ☐ IP-addresses and/or device type ☐ Job information ☐ Location data ☐ Race or ethnicity ☐ Political opinions ☐ Physical or mental health ☐ Information about a person's sex life or sexual orientation ☐ Religious or philosophical beliefs ☐ Membership of a trade union ☐ Biometric information ☐ Genetic information ☐ Other (please explain below):
4.5 Technical/organisational measures Select which of the following security measures are used to protect personal data.	☐ Pseudonymisation ☐ Anonymisation ☐ File encryption ☐ Encryption of storage ☐ Encryption of transport device ☐ Restricted access rights ☐ VPN ☐ Regularly scheduled backups ☐ Physical locks (rooms, drawers/file cabinets) ☐ None of the above ☐ Other (describe below):
4.6 Will any personal data be transferred to organisations within countries outside the European Economic Area (EU, Norway, Iceland and Liechtenstein)? If the research takes places in a country outside the EU/EEA, then please also indicate this.	Yes/no If yes, please fill in the country.
5 – Final comments	
Do you have any other information about the research data that was not addressed in this template that you think is useful to mention?	No, if something does come up later in the research this will be edited.