‘From Gas Grids to Hydrogen Hubs:

Insights from the Northern Netherlands’

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**Summary**

In the late 1950s, the Dutch discovered their natural gas reserves and created one of the most complex and expansive gas grids in the world. Today, the existing gas infrastructure is being repurposed to leverage a second gas revolution: traditional fossil fuels are being superseded by green hydrogen. This marks a significant shift towards sustainable energy solutions.

This qualitative research investigates factors shaping the innovative landscape of the Northern Netherlands and poses the following research question:

*'How does green hydrogen innovation in the Northern Netherlands diffuse?'*

This question is answered by examining the roles of publicly-funded institutions and startups in the transition to a hydrogen-based energy-system.

The research employs the Diffusion of Innovation (DOI) theory and the Multi-Level Perspective (MLP) to dissect the variables influencing green hydrogen diffusion. The DOI theory outlines five main factors affecting the diffusion of technological innovation: relative advantage, complexity, compatibility, trialability and observability. These factors are integral to the MLP framework, which provides a comprehensive view of the multi-dimensional changes in socio-technical systems. The DOI factors shape the innovation dynamics at the different levels in which the transition occurs. At the micro-level, niches for green hydrogen innovation are influenced by 'relative advantage' and 'trialability' of new technologies. At the meso-level, socio-technical regimes are shaped by the 'compatibility' and 'complexity' of integrating hydrogen solutions within existing infrastructures and regulatory frameworks. The macro-level

socio-technical landscape is shaped by the 'observability' of successful innovations which drives the policy and market conditions that facilitate widespread diffusion. These frameworks elucidate the process of green hydrogen diffusion throughout the Northern Netherlands.

The study uses purposive sampling to recruit a group of eight interviewees from publicly-funded institutions and startups. Semi-structured interviews are conducted and analysed by coding themes derived from the theories and interview transcripts.

Publicly-funded institutions bridge research and practical application, aiding startups in advancing green hydrogen technologies and informing policy-making. Startups drive the technical development of innovation, providing test beds for new technologies and tailoring them to regional needs. Together, these public and private entities shape the ecosystem that underpins the development of a green hydrogen-based energy-system in the Northern Netherlands.

Policy recommendations include measures to support supply and demand, the clarification of procedures to apply for subsidies, networking opportunities, and infrastructure investment. These policies would position the Northern Netherlands as a critical global green hydrogen hub.

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# Introduction

## 1.1 Background

21st century innovation is increasingly defined by the need to tackle 'grand challenges'. Among these, climate change stands out as being particularly 'wicked' in the sense that it is complex, systemic, interconnected, and urgent (Mazzucato, 2018). According to NASA, 2023 was the warmest year since 1880, and the past ten consecutive years have been the warmest ten on record (NASA, 2024). A main issue in addressing climate change lies in limiting the rise in the global average temperature and thereby focuses on reducing the amount of greenhouse gas (GHG) emissions. Unsurprisingly, targets concerning renewable energy have taken a central position in the international political agenda. For instance, the European Union's (EU) Renewable Energy Directive (RED III). RED III's main objective is to increase the EU's share of renewables in energy production to a minimum of 42.5% by 2030 (European Commission, 2024). The directive requires the EU member states to transpose it through their own targets and domestic energy policy. In this respect, green hydrogen emerges as a promising yet underutilised alternative to fossil fuels.

Green hydrogen is an unparalleled energy carrier due to its high energy density and clean combustion (Zhang et al., 2024). Its versatility in use makes it a multifaceted solution to modern energy demands. Hydrogen can store excess renewable energy, maximising renewable resource use and ensuring energy security (Karduri, Ananth, 2020). Yet, realising its contribution to the global energy mix in the 21st century is not straightforward. Favourable conditions for its penetration must be in place. The spreading of green hydrogen is a monumental task necessitating collaboration among governments, industry, and the scientific community.

A fundamental gap in energy transition literature is the oversight of its complexity resulting from interactions between elements of the entire system. Focusing on individual subsystems obscures the holistic picture. This research pays special attention to the DOI elements that play an important role in shaping the dynamic system and analyses the system from a Multi-Level Perspective.

## 1.2 Research Problem

Wicked problems often arise from social constructions and conflicting perspectives held by stakeholders, leading them to focus on their own bounded interests. Varying levels of knowledge about climate change deepen divisions between them (Boezeman, 2016). Tackling climate change therefore requires intricate coordination and consensus-building among actors from various disciplines, sectors, and scales (Patton, 2011). As noted by Brown, Harris and Russel (2010), wicked problems cannot be solved by the same tools and processes that have created them. This highlights the need for innovative sustainability solutions that forge new paths.

Among these innovative strategies, Hydrogen Valleys stand out. These regions integrate production, distribution, and usage to create localised energy-systems. This approach embeds hydrogen technologies within local economies and communities, thereby contributing significantly to the social relevance of its study. The Northern Netherlands is notable in its ambition to establish itself as a leading European hydrogen ecosystem. The contribution of green hydrogen in the Northern Netherlands is largely determined by the rate and manner by which innovations diffuse through the Hydrogen Valley ecosystem.

The central research question is therefore:

*'How does green hydrogen innovation in the Northern Netherlands diffuse?'*

Key stakeholders in the Hydrogen Valley ecosystem are publicly-funded institutions and startups. Addressing wicked problems requires research that enhances learning about transformations (Fazey et al., 2018). By working to identify optimal policies, publicly-funded institutions bridge the gap between research and practical applications. On the other hand, startups drive the energy transition, piloting and tailoring innovation for commercial viability. Therefore, measuring energy startup activities captures the energy-transition's impact (Singh et al., 2021). These public and private entities shape the landscape in which green hydrogen diffuses. By examining their roles, this study intends to highlight both the opportunities and challenges accompanying green hydrogen growth. In doing so, the research aims to determine what conditions foster and hinder the successful diffusion of green hydrogen innovation in the Northern Netherlands.

The sub-questions are:

> *'What is the role of publicly-funded institutions in the diffusion of green hydrogen innovation in the Northern Netherlands?'*
>
> *'What is the role of startups in the diffusion of green hydrogen innovation in the Northern Netherlands?'*

## 1.3 Structure of Thesis

The remainder of this thesis is organised into four chapters. Chapter 2 will lay out the main theories that anchor the study and draw expectations from the literature. Chapter 3 sets forth the qualitative methodology employed for data collection. Chapter 4 analyses the results and comes to the conclusions presented in Chapter 5. The thesis will conclude by suggesting areas for further research and policy recommendations.

# Theoretical Framework

## 2.1 DOI and MLP

This research deals with the 'diffusion' of 'green hydrogen 'innovation'. 'Innovation' is "something newly introduced, such as a new method or device" (Collins, 2021). 'Green hydrogen' is hydrogen obtained through renewable sources (Zhou et al., 2022), and 'diffusion' is "the process by which an innovation is communicated through certain channels over time among members of a social system" (Rogers, 1995). The phenomenon describes how an innovation spreads. The Diffusion of Innovation (DOI) theory outlines five main factors that affect the adoption of technological innovation: relative advantage, complexity, compatibility, trialability and observability (Rogers, 2003). The end result of diffusion is the adoption of green hydrogen innovation to substitute fossil fuels, minimising the emission of GHG and addressing the wicked problem of climate change. However, the socio-technical transition to a hydrogen-based energy-system does not come about easily. Industrial economies have become stuck in fossil-fuel-based energy-systems through technological and institutional co-evolution, a concept coined as 'carbon lock-in' (Unruh, 2000). This lock-in can explain the slow diffusion of carbon-saving technologies, like green hydrogen. The MLP framework comprehensively analyses the multi-dimensional changes in socio-technical transitions to sustainability. The MLP distinguishes three levels through which innovation diffuses: niche innovations at the micro-level, socio-technical regimes at the meso-level, and the socio-technical macro-landscape (Geels, 2005). Together, the DOI and MLP theories examine how technological innovations spread and the dynamics of the landscape in which they do so.

At a micro-level, the Hydrogen Valley niche acts as a 'protective space' that nurtures learning and development processes of path-breaking innovations so they are able to compete with more dominant existing systems (Smith & Raven, 2012). This involves helping niche innovations gain competitive strength by making them profitable within the existing regime ('fit and conform') or changing the mainstream selection environment to favour these innovations ('stretch and transform') (Smith & Raven, 2012). These empowerment mechanisms help green hydrogen scale-up and diffuse.

The 'fit and conform' and 'stretch and transform' processes within the Hydrogen Valley niche relate to the DOI characteristic 'relative advantage'. Relative advantage is "the degree to which an innovation is perceived as being better than the idea it supersedes" (Rogers, 2003). This can be measured in economic terms but also in terms of satisfaction. Empowerment mechanisms make green hydrogen innovation cheaper, contributing to a higher relative advantage. The Horizon Europe programme, a 100-billion-euro investment fund, is an example of funding with a prominent focus on making hydrogen commercially competitive by stimulating research, technological development, and demonstration projects (RVO, 2022). Under this programme, the Northern Netherlands was the first region to receive 9-billion-euros for its 'Hydrogen Valley' (RVO, 2022). Such funding mechanisms help green hydrogen to 'fit and conform' by performing profitably within the existing regime. The process to 'stretch and transform' relates to the perceived sustainability of green hydrogen innovation. Green hydrogen's storage potential is a competitive advantage over fossil fuels. While renewable energy offers tangible solutions for reducing GHG emissions, it intensifies the supply variability and intermittency (Pommeret, Schubert, 2019). Energy storage is deemed a solution for grid stabilisation and uninterrupted energy supply. In hydrogen storage systems, excess electricity can be converted to hydrogen, stored, later producing electricity (Becherif et al., 2015). Policies that obligate industry to scale-up renewable energy use support the market selection of green hydrogen, thus its diffusion.

The niche environment contributes to a higher relative advantage by offering space that encourages trials. The DOI presents 'trialability' as "the degree to which an innovation may be experimented with" (Rogers, 1995). Prototyping in the early phases of development reduces uncertainty for new technologies (Hendry et al., 2010). Trialing is expected to accelerate diffusion of green hydrogen innovation as it reduces risks and leads to superior products. Therefore, mission-oriented initiatives within experimental platforms often hold a transformative sustainability ambition (Haddad et al., 2022).

At the meso-level, the MLP refers to the socio-technical system within which innovation must survive. This includes the institutions, rules, and networks that steer and limit green hydrogen innovation development (Geels, 2005). Green hydrogen innovation should be compatible and well-understood to survive in the socio-technical system. Compatibility describes how consistent the innovation is with "the existing values, past experiences, and needs of potential adopters" (Rogers, 2003). The discovery of the Groningen gas-field in 1959 transformed the Netherlands' energy network (Goossens, 2017). However, large-scale gas production-induced earthquakes led to significant debate and closure of the gas field in 2024 (Wright, 2024). Repurposing the region's existing gas infrastructure to hydrogen must be technically feasible and socially acceptable. Research indicates that the current natural gas network meets minimum technical requirements for hydrogen distribution (Arends, 2020). The gas-induced earthquakes laid bare the controversies inherent in dealing with natural gas in the age of climate change. These past experiences potentially foster a sentiment in favour of transitioning to a hydrogen-fuelled system. However, lack of transparency and accountability may have instilled regional distrust in publicly-funded institutions as they introduce a new gas. Research emphasises the importance of public trust in institutions (Zavestoski et al., 2002). Low levels of trust in institutions and rules in the Northern Netherlands would limit the diffusion of green hydrogen innovation.

The more complex innovation is, the more limiting the rules and networks become. Complexity is "the degree in which the innovation is seen as difficult to understand and use" (Rogers, 2003). Complexity is expected to correlate negatively with diffusion rates. The shift in energy-systems introduces uncertainties for stakeholders, especially regarding implementation of a hydrogen supply chain (Schlund et al., 2022). Recognizing that research is an important driver of growth, the idea arises that publicly-funded institutions should adopt an entrepreneurial mission beyond teaching and research (Czarnitzki et al., 2016). Publicly-funded institutions produce knowledge that can be used to facilitate and improve decision-making. This study will explore how publicly-funded institutions collaborate with startups to kick-start the green hydrogen market.

Finally, the macro-level encompasses the exogenous socio-technical landscape in which large-scale developments occur (Geels, 2005). The wider context includes the Dutch government's ambitious climate targets, the European decarbonization strategy, and the global shift towards renewable energy. Triggered by the Groningen earthquakes, the Netherlands pledged to lead the development of Europe's hydrogen backbone, aiming to connect north-western Europe by 2030 and all of western Europe by 2040 (ProvincieGroningen, 2020). Mazzucatto roots for an ambitious catalytic role of the government to proactively create new landscapes rather than merely fixing existing markets. By breaking new ground and bringing together different players, Hydrogen Valleys have the potential to 'crowd in' business investment, laying the groundwork for private investment (Mazzucatto, 2018). Enhancing expectations about future growth opportunities requires observing successful innovations, the final characteristic of the DOI theory. Observability is "the degree to which the results of an innovation are visible to others" (Rogers, 1995). Visibility stimulates discussion about new ideas, like green hydrogen, amongst startups in the Valley. It is therefore expected that greater observability leads to greater diffusion.

## 2.2 Conceptual Model

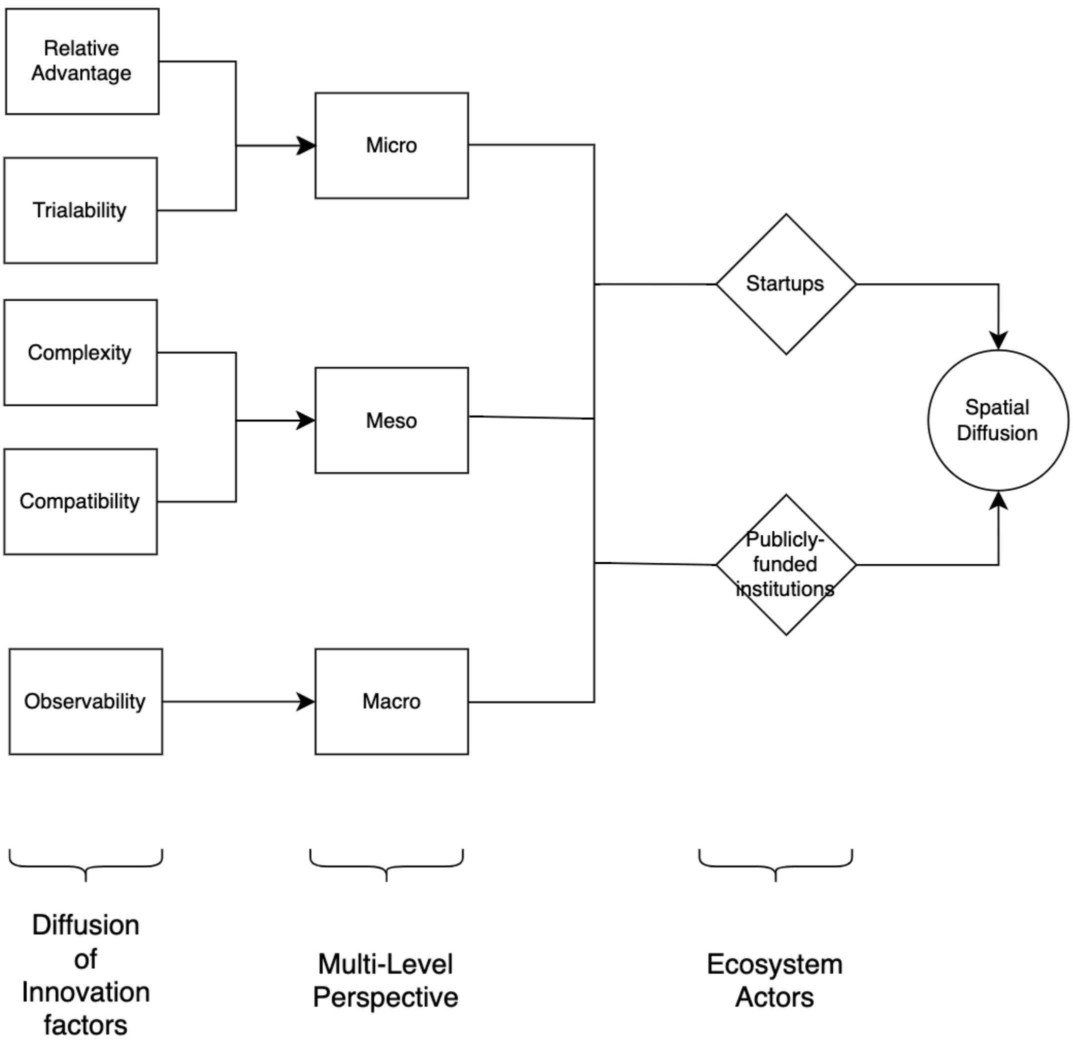



Figure 1: Conceptual model

As explained in Section 2.1, each factor from the DOI theory influences one main landscape level as presented by the MLP. The study focuses on two ecosystem actors: publicly-funded institutions and startups. These act within the landscape of the Northern Netherlands to deliver the spread of green hydrogen innovation.

### 2.3 Expectations

- The Hydrogen Valley acts as a 'protective space' to trial green hydrogen innovation which is expected to speed up diffusion.
- The available funding is expected to give green hydrogen a greater relative advantage over natural gas, speeding up diffusion.
- The perceived sustainability of green hydrogen is expected to give it a greater relative advantage over natural gas, speeding up diffusion.
- The high compatibility of green hydrogen with the Northern Netherlands region is expected to speed up diffusion.
- The complexity of green hydrogen innovation is expected to slow down diffusion.
- The high observability of green hydrogen innovation in the Hydrogen Valley is expected to speed up diffusion.

## Methodology

### 3.1 Research Method

This study employs a qualitative approach to investigate the diffusion of green hydrogen innovation in the Northern Netherlands. Data collection began with desk research, consulting literature via key search terms mostly in Google Scholar, Scopus, and ScienceDirect. This provided a foundational understanding of the energy transition. Preliminary research pointed out that one way in which the government aims to commercialise clean energy technologies is by stimulating an "innovation ecosystem" that promotes cooperation and open shared resources between public and private organisations (Engel-Cox et al., 2022). Some researchers argue that government policy has an even greater impact on technological development than market forces

(Wiser, 2000). This raised questions about how a Hydrogen Valley fosters an innovative ecosystem, the role of public-private entities within this ecosystem, and the nature of policy in the context of the Northern Netherlands.

A purposive sampling strategy was used to select participants most likely to provide appropriate and useful information (Kelly, 2010). This used limited research resources effectively (Palinkas et al., 2015). After encountering non-response, snowball sampling was employed. With this approach, the initial contacts who fit the research criteria were used to establish contacts with others. Bryman et al. (2009) suggest that snowball sampling is suitable when researching a statistically small group. Snowball sampling increased the study's sample size and made it possible to include participants that the researcher previously had not known. Maps were created using GIS to visualise the geographical locations of the eight interviewees, revealing a clustered distribution. Notably, two startups and two publicly-funded institutions were located at the same site, suggesting collaboration within the Valley (Appendix 3).

Semi-structured interviews were conducted, using a set of predefined questions as a baseline for the interviews, yet giving participants freedom to introduce new ideas (Dadzie et al., 2018). Open-ended questions provided flexibility to expand on areas the participants were knowledgeable about (Appendix 1). Scholars such as Kallio et al. (2016) emphasise that the interview guide "offers a focused structure for the discussion during the interviews but should not be followed strictly". The study included eight semi-structured interviews lasting between 35 and 55 minutes. Interviews were conducted in person where possible and via Zoom to accommodate varying preferences of interviewees.

### 3.2 Data Analysis

The data analysis began with thorough familiarisation with the collected data by transcribing the interviews and uploading them into Atlas.ti. Subsequently, a coding tree was developed, anchored in the theoretical frameworks of the study (see figure 2). Codes A1 to A3 symbolise the landscape level the quotations relate to, deduced from the MLP. Codes B1 to B5 are the five key factors influencing diffusion presented by the DOI theory. Codes C1 to C11 are induced from the interviews and form the key, recurring themes presented by the interviewees. Important quotations from the eight transcribed interviews were coded to A and B codes. This way, the researcher could easily evaluate which DOI elements had the greatest influence on each MLP landscape level. All coded groups could also be separated according to which type of actor (publicly-funded/startup) spoke of this.

Emergent conclusions were mapped against the research expectations to determine whether the developed themes supported or contradicted expectations. Finally, the thematic analyses and insights were reported in a coherent narrative as presented in the Results Chapter hereafter.

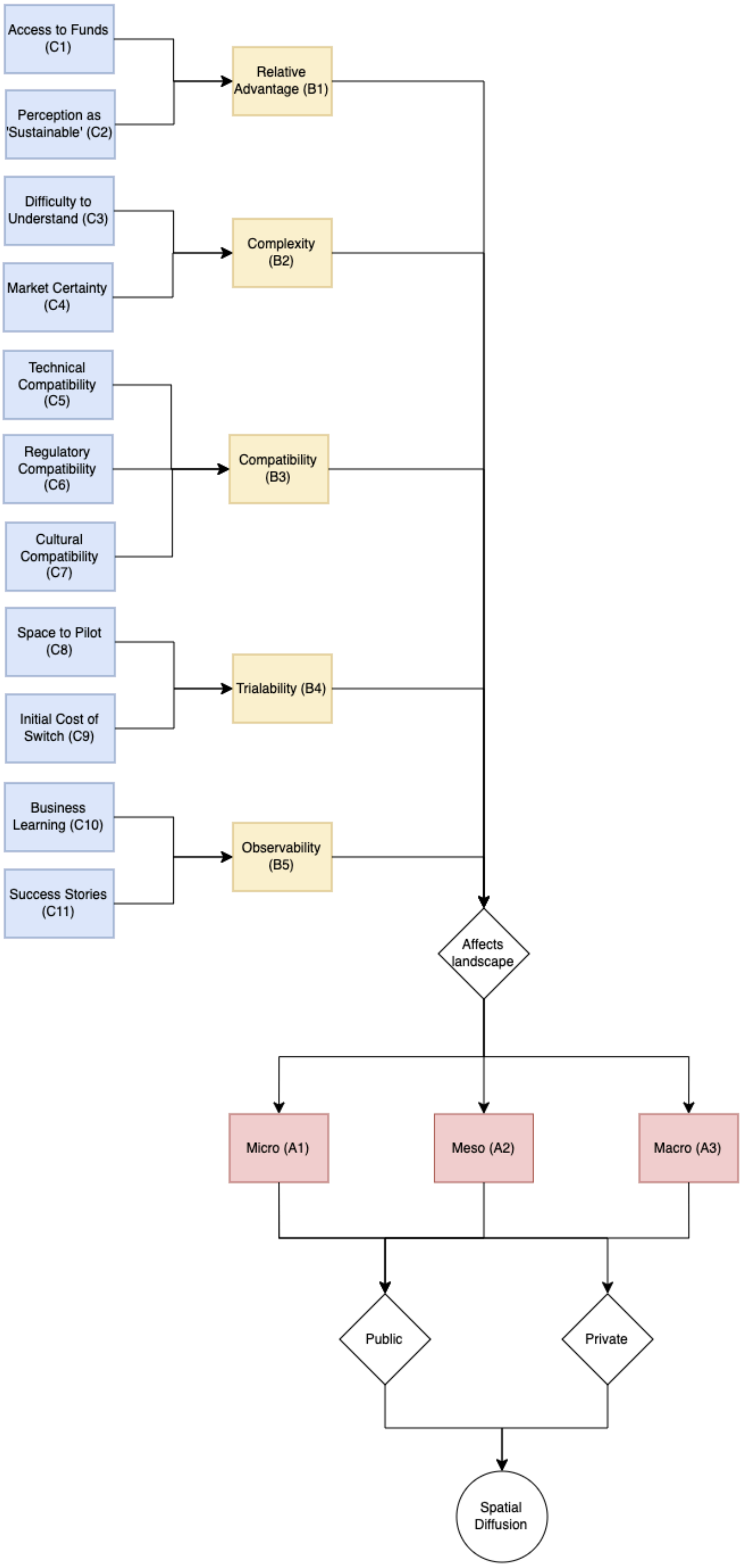



Figure 2: Coding tree

### 3.3 Quality of Data

Purposive sampling is typically used in qualitative studies to achieve depth of understanding (Patton, 2002). The subjects in this research were selected based on the study's purpose to examine how green hydrogen innovation diffuses in the Northern Netherlands. By interviewing four subjects working in publicly-funded institutions and four for startups, it was expected that each participant would provide valuable information on their roles in the Hydrogen Valley. However, purposive sampling includes the non-random selection of participants, which inhibits the ability to draw inferences about the entirety of actors involved in the diffusion process. As for snowball sampling, participants might not have based their referrals on subjects who fit the research criteria, but on the perception that the new recruit would be a willing contributor (Parker et al., 2019). The limited sample size of eight is insufficient to ensure full coverage of issues in the diffusion of green hydrogen innovation in the Northern Netherlands. However, this type of qualitative research, as Mason (2010) says "is concerned with meaning and not making generalised hypothesis statements". Participants interpret their experiences, and even with limited research resources, the researcher can group similar expressions of meaning under headings that seem relevant to the research question grounded in theory from the literature review. Future research should continue until it achieves 'saturation', when the researcher is confident no new data relevant to the research question would emerge if more interviews were conducted (Glaser, Strauss, 1967). The risk of subjectivity could also have tempted the researcher to ask leading questions, resulting in biased responses. The flexibility can lessen the study's validity as greater deviation from the topic makes it harder to compare participant responses. However, while it is important to bear these limitations in mind, it is also the open-ended nature that stimulated new ideas and provided rich responses from participants. The greatest difficulty faced in the analysis resulted from the competitive nature of innovation. Startups were unwilling to share information about their off-takers, limiting the diffusion flows' spatial dimension. Therefore, the research placed greater emphasis on the manner in which innovation diffuses in the Northern Netherlands than where it spreads to.

### 3.4 Ethical Considerations

Data collection was done so that potential risks of harm-doing were minimised. Before conducting interviews, participants were asked for their genuine consent by signing a consent form (Appendix 5). Consent was given freely, as an opt-in. The study's purpose, the use of data and participants' rights were specific. Only the researcher and supervisor have access to personal data. To treat interviewees' personal boundaries with respect, a descriptive statistic and map are provided without revealing the identities of interviewees (Appendix 2, Appendix 3). Once secured, data was removed from the recording instrument. After the research is completed, all datasets will be deleted.

## Results

This section presents the empirical results obtained from the semi-structured interviews in three sections, according to their landscape levels. The influence of the first variables 'trialability' and 'relative advantage' on the micro-level will be presented in section 4.1, followed by the influence of 'compatibility' and 'complexity' on the meso-level in section 4.2, and lastly the 'observability' of successful innovations on diffusion at the macro-level in section 4.3.

### 4.1 DOI at the micro-level

The Hydrogen Valley was expected to act as an incubation room to trial innovation, thereby speeding up diffusion of green hydrogen innovation. Indeed, radical innovations are generated, tested, and diffused inside the niche. The Valley acts as a protected space where the learning process is facilitated without being undermined by the established market (Belaïd, Al-Sarihi, 2024). While the data underscores the importance of trialability in the Northern Netherlands, significant investment is necessary to support the innovative efforts of startups.

Prior to market entry, startups are unaware of whether or not their ideas will work. Nearly 90-billion-USD is required by 2026 to support the research and development and demonstrations of critical technologies to achieve net-zero by 2050 – roughly half of which is necessary to make hydrogen technologies market-ready (IEA, 2022).

One such investment is in the Northern Netherlands Hydrogen Valley. The undertaking was allocated a subsidy of 20-million-euros with a public-private co-financing of 70-million-euros to develop a green hydrogen chain (Gasunie, n.d.). The Valley is in itself an experimentary area to study, simulate and test the potential of the hydrogen economy. Its main objective, as explained by an interviewee of the Wubbo Ockels School for Energy and Climate, is to develop a replicable business model for the wide-scale commercial implementation of hydrogen throughout the regional energy-system.

Trialability is therefore of great importance in the Hydrogen Valley. In fact, the same interviewee concluded that:

*"Valleys are per definition short-term solutions to test the potentials of a new socio-economical technical development, such as the hydrogen technology for the energy transition. And, if successful, then you get upscaling. So from one valley to valleys, and from isolated valleys to*

*corridors, connections, areas, mainstream economy."* (Wubbo Ockels School for Energy and Climate)

Two key conditions emerged from the data as necessary for startups to test their innovations in the Northern Netherlands: space to pilot, and investment. Groningen Seaports was interviewed about the facilities it offers startups to pilot and demo their projects. Seaports recognises the importance of startups to a region's economic development. It offers an attractive business climate by helping startups with permit procedures, hosting a close-knit network, and collaborating with publicly-funded knowledge institutions to facilitate innovations. In this way, the niche Hydrogen Valley provides spaces to build social networks so startups can learn by doing and interacting. However, the main issue startups face in trialling their innovation is the high cost. Public efforts from the European Hydrogen Bank were identified as supportive of startups switching to the production of green hydrogen. For example, the government-backed minimum prices where the state initially buys expensive hydrogen and sells it to consumers at lower prices (Wolf, 2023). This renders economic viability. Additionally, two interviewees mentioned the NOM as a key source of investment. This was the only regional investment agency in the Northern Netherlands identified, signifying a lack of regional investment. Consequently, startups experience difficulty in finding funding to realise their plans.

The initial relative advantage of adopting green hydrogen is minimal in economic terms. This is often the case when introducing new technology (Hall, 2004). Startups presented the challenges of obtaining public funding. The current administrative burden limits access to funds, hampering diffusion. One interviewee mentioned:

*"Private funding that is much more accessible, much cheaper, much quicker."* (Hydrogen

Prospect)

Thus, in order for green hydrogen to be perceived as better than fossil fuels, its value should come from aspects that are not measured in monetary terms. A recurring concept in the data was hydrogen's potential to store energy. Grid congestion is an increasing challenge in the Netherlands, as the capacity limits of the grid restrict utilisation of electricity generated from renewable sources. However, as an energy carrier, hydrogen can store the surplus electricity produced by these renewable sources. Positioning hydrogen as a key balancing element within the energy mix would contribute significantly towards the Netherlands' ambitious climate targets. Additionally, the ambition to be part of the energy transition was mentioned as an important stimulant to develop green hydrogen. However, a general consensus was found that:

*"The high price, it doesn't cover the additional value."* (Summit Engineering)

This indicates that hydrogen's storage potential and perceived sustainability do not weigh up to its high costs. Current relative advantage of green hydrogen remains low. This necessitates the need for effective funding mechanisms to offset the transition's cost. This would stimulate more innovation, thus learnings within the Valley.

## 4.2 DOI at the meso-level

The research expected green hydrogen innovation to be highly compatible with the socio-technical landscape of the Northern Netherlands. High compatibility signifies consistency with the values, experiences, and needs of a region (Rogers, 2003). A high compatibility helps new innovation diffuse through the socio-technical system. Three key themes emerged from the data regarding the compatibility of green hydrogen innovation with the socio-technical landscape of the Northern Netherlands: technical compatibility, cultural compatibility and regulatory compatibility. In broad terms, the data indicated high technical and cultural compatibility of green hydrogen, but an ill-fitted regulatory landscape.

The region's technical landscape is conducive to transforming into a green hydrogen ecosystem. Its proximity to offshore wind north of the Netherlands grants it access to affordable renewable energy, its coastal position provides access to import-export facilities, and concentrated energy infrastructure has been 'left behind' from the natural gas production. This presents great opportunities to be repurposed for hydrogen production.

Similarly, expertise in hydrogen, transport, and innovation builds on the Dutch position as leader in natural gas production. Startups can leverage the knowledge capital to steer development of green hydrogen technologies. The region's inhabitants are presented as being comfortable with energy projects. However, data also depicts notions of angst:

*"Provincial in our thinking and daring."* (Energy and Sustainability Research Institution Groningen)

This weary presentation of the Northern Netherlands contradicts the presentation of the "open, pragmatic and outward-looking" Dutch mindset by the RVO (RVO, 2021). Perhaps the diversion of the Northern Netherlands is shaped by its history of gas production and induced seismicity. The government's lack of accountability and failure to compensate for damage caused by earthquakes reduces confidence in the introduction of a new gas like hydrogen.

While regulatory framework conditions have been identified as critical factors influencing innovation activities (Blind, 2012), data pointed to a tension between innovation and regulation:

*"Technology evolves faster than the law. The law is a very slow process, takes a very long time to make amendments and adjustments etcetera. It's not necessarily quickly adapted, so to say. Which means that many innovative technologies are ill-fitted in the current legislation… the problem is very often the lack of legislation which makes its investment very risky."* (Groningen Centre for Energy Law and Sustainability)

The market demands swift action but the government camps with strict administrative requirements. In an age of continuous, complex, and disruptive technological innovation, technology evolves faster than the law. In literature, this has been termed a 'pacing problem' (Fenwick et al., 2017). In the Northern Netherlands, this translates into a lengthy subsidy approval process. Most probably, the process will smoothen through a process of trial-and-error. Close collaboration with knowledge institutions is important to take learnings and update policies.

The limiting institutional landscape and rules that arise at the meso-level greatly result from green hydrogen's complexity. One of the biggest barriers to the diffusion of green hydrogen innovation is uncertainty. This is underlined by the following remark:

*"Its usage on a massive scale, is quite new and at all levels of the chain there are so many questions that we still have to answer, and so many questions that we still have to formulate that explain why there is a lot of uncertainty still around the hydrogen economy and also why it is so difficult to use and develop it fully."* (Wubbo Ockels School for Energy and Climate)

This stresses the wickedness of the problem of climate change and its constantly evolving solutions. Lower market and technical understanding increases the risk of diffusion failure (Hall, 2004). The complex hydrogen market is plagued by persistent ambiguity. Data presents a clear chicken-and-egg scenario, with producers and off-takers waiting for the other to scale-up. The hydrogen producer wants to know if there is a market, and off-takers want to know if there will be green hydrogen. The high costs and risks for both producers and off-takers further hinders market development. Producers seek long-term agreements to build electrolysers, while consumers are hesitant to commit to such high-cost, long-term agreements. Policy should therefore support both the supply and demand side.

The supply-demand mismatch necessitates efforts to connect stakeholders. These efforts are most prominently taken by the New Energy Coalition, which acts as a hub with an extensive network of 150 partners (Interreg, 2023). Traditionally, collaboration amongst startups has remained limited as they work in-silos. However, collaboration is said to be a means towards the penultimate goal of solving complex challenges. It gives firms a strategic, sustainable, and profitable platform (Gardner, 2016). With knowledge changing faster than ever, professionals must specialise to keep current. Innovation is at the heart of every startup (Reis, 2011). Research and practical experimentation yield new knowledge and new methodologies. There are limits to the depth of knowledge and skill that can be achieved by anyone. The innovative process of startups is impaired by limited financial means, competencies, and insufficient understanding of the newest technologies. Thus, startups need to collaborate more to remain innovative. By doing so, startups can feed off each other, share information, and enrich each other's expertise.

Continuous dialogue and collaboration at the meso-level is crucial to mitigate complexity, as it fosters a better understanding and smoother adoption process. Data points to the bidirectional link between knowledge and policy. Knowledge serves as an input to better understand the problems policy aims to address, and policy forms the framework for developing new knowledge. Sustainable solutions for highly complex challenges depend on scientific expertise and research. Publicly-funded institutions can provide startups with scientific knowledge on which to judge feasibility of developments in this complex landscape.

### 4.3 DOI at the macro-level

Finally, it is expected that the observation of successful innovations helps shape new green hydrogen markets at the macro-level. The OECD presents how governments can lay the ground for the diffusion of green hydrogen by implementing policies that support demonstration policies (Cammeraat et al., 2022). Observability can 'crowd in' private investment. Some interviewees presented the Hydrogen Valley as being foremost a communication tool to showcase the potential of green hydrogen ecosystems. However, the vast majority agreed that:

*"There are many plans and everyone talks about hydrogen, but little investments. That's annoying because it creates a certain bubble that can burst. And because Northern Netherlands was spearheading this kind of hydrogen economy, hydrogen valley concept until recently. So, the hope was that it will be followed up with real investments and they have all these plans and publications, how many millions should go and how many are needed. But they never, in my opinion, really took place. Or not yet. And we see that the rest of the world is also not, of course, standing still. Things are happening that go actually beyond the plans."* (Groningen Centre for Energy Law and Sustainability)

Data on the observations aligns with earlier discussions on trialability in the sense that real innovation is still confined to ideas, without execution. For green hydrogen innovation to truly diffuse, the ambitious plans must be followed-up by investment and implementations.

## Discussion

### 5.1 Conclusion

To conclude, the complexity of funding applications reduce hydrogen's relative advantage, making it difficult to justify the high costs. Market uncertainty, caused by price disparity between off-takers and producers, further hinders diffusion. Additionally, the complexity of green hydrogen innovation in the Northern Netherlands deters investment. To leverage the region's technical compatibility and strategic spatial location, policy should support innovation. This would increase trials and observability of green hydrogen solutions in the Hydrogen Valley.

Publicly-funded institutions like the New Energy Coalition bridge the gap between research and practical applications by connecting startups with the resources and knowledge needed to develop green hydrogen innovation. They also inform policy decisions to enhance the regulatory framework, supporting the compatibility and implementation of green hydrogen solutions.

Startups, on the other hand, drive the technical development of these innovations, tailoring them to the specific needs of the Northern Netherlands. They provide vital test beds for piloting new technologies and collaborate for scalability. Together, these public and private actors shape the ecosystem that fosters the development of a green hydrogen-based energy-system in the Northern Netherlands.

The research expected to find a high relative advantage of green hydrogen innovation due to available funding and its sustainable potential. However, data rejects this expectation. While projects in the Valley heavily rely on funding, this is oftentimes inaccessible to startups. The sustainability does not cover the high costs.

The complexity of emerging green hydrogen technologies expected to negatively correlate with diffusion. Indeed, policy in the Northern Netherlands is ill-fitted to innovation. However, research by publicly-funded institutions helps tackle the complexity of green hydrogen innovation, easing its diffusion.

High compatibility with existing systems and values in the Northern Netherlands was expected to facilitate the diffusion of green hydrogen. Mixed interpretations regarding its alignment with regional values were presented. There is substantial knowledge capital, but also a distrust in the government due to issues stemming from natural gas production. Technically, green hydrogen can integrate with the existing natural gas infrastructure. Nonetheless, the innovation faces incompatibility with the current regulatory framework.

Trialability and observability of green hydrogen was expected to positively correlate with its diffusion. While many plans in the region exist and the valley offers space to trial, there is little follow-up investment. This means that few trials actually take place, and observability remains low.

## 5.2 Strengths and Weaknesses of the Study

The research question uses broad terms which were clarified at the start of each interview to ensure all interviewees shared a common understanding. The qualitative research method is suitable as it effectively reveals situations, perceptions and experiences (Kumar, 2011) of employees from publicly-funded institutions and startups. Semi-structured interviews provided participants with the opportunity to offer more explanation and clarification. It allowed the researcher to observe and identify perceptions not initially included in the study. The researcher successfully addresses gaps in literature by conducting a multi-dimensional analysis of the interactions between elements essential to green hydrogen development within a Hydrogen Valley.

A key criticism of the qualitative research method is rooted in interpretivism. This claims that a researcher cannot be completely separated from their individual values and beliefs during a study (Kivunja & Kuyuni, 2017). The subjectivity inherent to the qualitative approach potentially limits the study's generalisability. For example, building key thematic concepts from the interviews ('C' codes in figure 2) influences what can be considered the reality of the diffusion process in the Northern Netherlands. Furthermore, the small sample size limits the generalisability of the study. Future researchers may consider increasing the number of participants to enlarge the scope of their conclusions.

The competitive tensions between firms in the emerging green hydrogen market of the Northern Netherlands led participants to share little information about their off-takers. This limited insights into the geographical flows of their innovations. Future research could collect quantitative data on patents, revealing where the innovation spreads to by analysing the geographical distribution of patent filings. Collaborative patents could signify international collaboration. It would be interesting to investigate cross-border collaboration with Lower Saxony, given its geographic proximity and significant role in the hydrogen market. That information would support this study's observations about the dynamics and synergies crucial for the diffusion of green hydrogen innovation from the Northern Netherlands.

### 5.3 Policy Recommendations

Policy should support the production, transport, and off-take of green hydrogen innovation to solve the market's chicken-egg problem and stimulate innovation.

On the supply side, various subsidies for hydrogen production have been implemented, most notably the OWE scheme. In 2023, this allocated nearly €250 million subsidies to support electrolysers, a large part of which to realise small electorlyser projects the Northern Netherlands (RVO, 2023). However, data indicates some startups lack clarity in subsidy applications. It should be promoted that the Netherlands Enterprise Agency (RVO) can address queries and organises information sessions. In this way, assistance can assure policy, leveraging the role of startups in driving technological innovation.

The biggest challenge is lack of demand for green hydrogen. Instruments like the Jaarverplichting (annual hydrogen usage obligations in industry) aim to kick-start a hydrogen market (Rijksoverheid, 2021). The government should continue stimulating industry to adopt green hydrogen through subsidies and obligations. However, these obligations should be phased-in to avoid harming competitiveness and causing carbon leakage, whereby businesses transfer their production to countries with more lenient emission constraints.

Furthermore, networking needs attention for startups to initiate collaborations. The government should support more networking events like the Hydrogen Summit, which facilitates matchmaking sessions between producers and off-takers (European Commission, 2024).

The transition to green hydrogen is a global challenge that requires close international cooperation. Currently, limited international hydrogen trade exists (Skovgård Møller et al., 2023). Investment should focus on infrastructure, such as financing ports like Eemshaven to support the import and export of green hydrogen. This would position the Northern Netherlands as a critical hub in the global green-hydrogen supply chain.

**Appendix**

***Appendix 1 Interview Guide***

Brief introduction of myself, research and clarification of consent

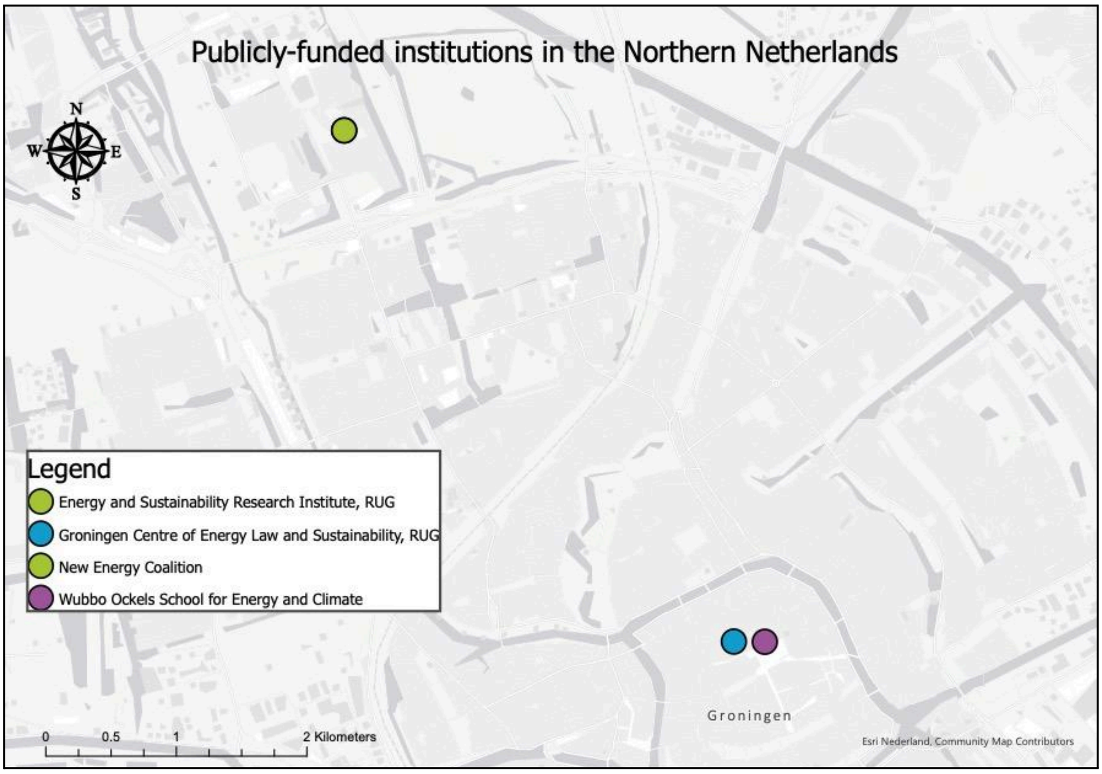
- Can you briefly describe your role and how it relates to the hydrogen industry in the Northern Netherlands?
- From your perspective, what have been the most significant developments in green hydrogen in the Northern Netherlands?
- Why did your organisation choose to locate in the Northern Netherlands?
- What do you believe to be the main drivers to the spread of hydrogen technologies in the Northern Netherlands?
- Where do most hydrogen technologies from the Hydrogen Valley in the Northern Netherlands spread to?
- What role does your organisation play in the spread of hydrogen technologies?
- Success stories?
- Failure stories?
- What actors do you collaborate with within the Hydrogen Valley?
- What have been the biggest barriers you have faced in facilitating the spread of hydrogen technologies in the Northern Netherlands?
- How has policy facilitated or hindered you in the development of green hydrogen innovation?
- Looking ahead, what would be needed to further support the diffusion of hydrogen technologies from the Northern Netherlands?
- Are there any additional thoughts, comments, or insights you would like to share regarding the diffusion of hydrogen technologies or any related topics we haven't

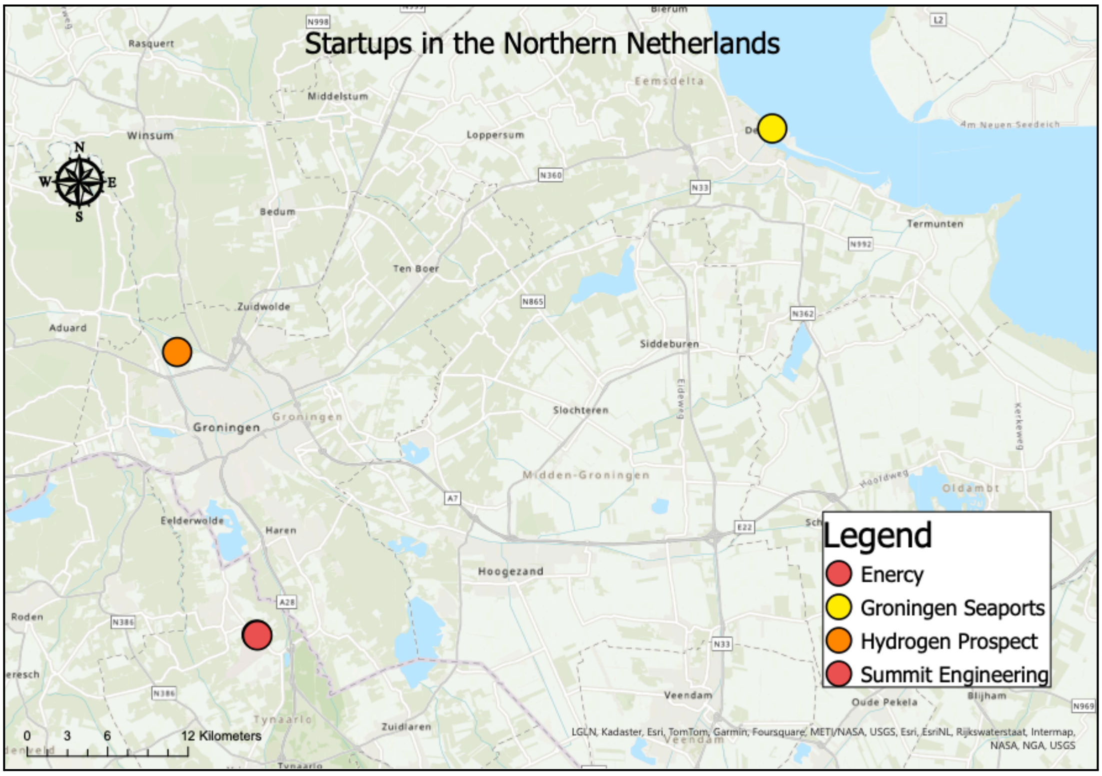
covered?

## *Appendix 2 Anonymised Interviewees*

| Type of Actor | Name of Organisation | N of employees | Location of Organisation | Nationality | Professional Background |
|---|---|---|---|---|---|
| Publicly-funded institution | New Energy Coalition | 50 | Nijenborgh 6, 9747AG Groningen | Dutch | Sustainable Energy System Management |
| Publicly-funded institution | Groningen Centre of Energy Law and Sustainability, RUG | 30 | Oude Boteringestraat 18, 9712GH Groningen | Swedish | Energy and Climate Law |
| Publicly-funded institution | Wubbo Ockels School for Energy and Climate | 8 | Grote Markt 21, 9712HR Groningen | Italian | European Environmental and Energy Law |
| Publicly-funded institution | Energy and Sustainability Research Institute, RUG | 19 | Nijenborgh 6, 9747AG Groningen | Dutch | Rural Agricultural Transition |
| Startup | Summit Engineering | 8 | Burgemeester J.G. Legroweg 45A, 9761TA Eelde | Dutch | Natural Gas Industry |
| Startup | Hydrogen Prospect | 5 | Zernikepark 12, 9747AN Groningen | American | Oil and Gas Industry |
| Startup | Enercy | 8 | Burgemeester J.G. Legroweg 45A, 9761TA Eelde | Scottish | Environmental Management, the European Commission |
| Startup | Groningen Seaports | 100 | Handelskade Oost 1, 9934AR Delfzijl | Dutch | Sales |

## *Appendix 3 Maps of Interviewees*




Startups in the Northern Netherlands
Legend
Enercy
Groningen Seaports
Hydrogen Prospect
Summit Engineering
0 3 6 12 Kilometers
N
S
E
W
Groningen
Winsum
Bedum
Ten Boer
Loppersum
Middelstum
Rasquert
Zuidwolde
Aduard
Eelderwolde
Haren
Roden
Hoogezand
Slochteren
Siddeburen
Termunten
Veendam
Zuidlaren
Oude Pekela
Blijham
Eemsdelta
Midden-Groningen
Oldambt
Tynaarlo
LGLN, Kadaster, Esri, TomTom, Garmin, Foursquare, METI/NASA, USGS, Esri, EsriNL, Rijkswaterstaat, Intermap, NASA, NGA, USGS

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*Appendix 4 Information Sheet for Interviewees*

**INFORMATION SHEET**

**Spatial Diffusion of Innovation in the Hydrogen Industry**

Thank you for your interest in participating in this research. This letter explains what the research entails and how the research will be conducted. Please take time to read the following information carefully. If any information is not clear kindly ask questions using the contact details of the researchers provided at the end of this letter.

**WHAT THIS STUDY IS ABOUT?**
The research seeks to explore the spatial diffusion of hydrogen innovation, with a specific focus on the Northern Netherlands. The aim is to understand the factors influencing their diffusion. The research aims to include approximately ten participants, comprising researchers for publicly funded institutions and start-ups.

**WHAT DOES PARTICIPATION INVOLVE?**
Participation in this study involves a semi-structured interview of approximately 30-40 minutes, where you will be asked to share your insights and experiences related to the diffusion of hydrogen innovation.

**DO YOU HAVE TO PARTICIPATE?**
Your participation in this study is completely voluntary. You are free to withdraw at any time or choose not to answer any specific questions during the interview, without any consequences or having to provide a reasons.

**HOW WILL INFORMATION YOU PROVIDE BE RECORDED, STORED AND PROTECTED?**
All information collected will only be shared between the researcher (Wibbien Marseille) and the Bachelor Project supervisor (Milad Abbasiharofteh). Data will be stored securely in accordance with GDPR guidelines and accessible only to these two persons.

In order to analyse the interview, a transcription is necessary, necessitating the recording of the interview. The data obtained from these interviews will remain strictly confidential and will only be accessible to myself and the supervisor. The data will be stored on the encrypted server of the University of Groningen and on my own encrypted hard drive. This data will not be retained for longer than two months following the conclusion of this project (approximately mid-June), after which it will be permanently deleted.

**INFORMED CONSENT FORM**
You will be asked to sign an informed consent form if you agree to participate, affirming your understanding and voluntary participation in this study. Remember, you can withdraw at any time.

**WHO SHOULD YOU CONTACT FOR FURTHER INFORMATION?**
For any further information or questions, please contact:

Wibbien Marseille
E-mail: w.i.marseille@student.rug.nl
+31 6 3418 4166

university of groningen

*Appendix 5 Consent Form*

**INFORMED CONSENT FORM**

**Spatial Diffusion of Innovation in the Hydrogen Industry**

**Name participant:**

**Assessment**

- I have read the information sheet and was able to ask any additional question to the researcher.
- I understand I may ask questions about the study at any time.
- I understand I have the right to withdraw from the study at any time without giving a reason.
- I understand that at any time I can refuse to answer any question without any consequences.
- I understand that I will not benefit directly from participating in this research.

**Confidentiality and Data Use**

- I understand that none of my individual information will be disclosed to anyone outside the study team (researcher and supervisor) and my name will not be published.
- I understand that the information provided will be used only for this research.
- I consent to the recording of the interview for the purpose of transcription and analysis.

**Having read and understood all the above, I agree to participate in the research study: yes / no**

**Date**

**Signature**

---

To be filled in by the researcher

- I declare that I have thoroughly informed the research participant about the research study and answered any remaining questions to the best of my knowledge.
- I agree that this person participates in the research study.

**Date**

**Signature**

## *Appendix 6 Data Management Plan*

| 1. General | |
|---|---|
| 1.1 Name & title of thesis | From Gas Grids to Hydrogen Hubs: Insights from the Northern Netherlands. |

| 2 Data collection – the creation of data | |
|---|---|
| 2.1. Which data formats or which sources are used in the project? | Theoretical research, using literature and publicly available resources.<br>Semi-structured interviews. |
| 2.2 Methods of data collection<br>What method(s) do you use for the collection of data. | ☐ Structured individual interviews<br>☒ Semi-structured individual interviews<br>☐ Structured group interviews<br>☐ Semi-structured group interviews<br>☐ Observations<br>☐ Survey(s)<br>☐ Experiment(s) in real life (interventions)<br>☐ Secondary analyses on existing data sets<br>☒ Public sources (e.g. University Library) |

| 3 Storage, Sharing and Archiving | |
|---|---|
| 3.1 Where will the (raw) data be stored *during* research? | ☐ X-drive of UG network<br>☐ Y-drive of UG network<br>☐ (Shared) UG Google Drive<br>☐ Unishare<br>☒ Personal laptop or computer<br>☐ External devices (USB, harddisk, NAS) |
| 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<br>NB do not use a personal UG network or google drive for archiving data! | Not planning to retain data after I have completed the research. It will be deleted once research is finished (mid-June). |
| 3.3 Sharing of data<br>With whom will you be sharing data during your research? | ☒ University of Groningen: only with the supervisor<br>☐ Universities or other parties in Europe |

| 4. Personal data | |
|---|---|
| 4.1 Collecting personal data<br>Will you be collecting personal data?<br><br>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. |

| | |
|---|---|
| 4.2 What kinds of categories of people are involved?<br><br>Have you determined whether these people are vulnerable in any way (see FAQ)?<br>If so, your supervisor will need to agree. | My research project involves:<br><br>☒ Adults (not vulnerable) ≥ 18 years<br>☐ Minors < 16 years<br>☐ Minors < 18 years<br>☐ Patients<br>☐ (other) vulnerable persons, namely (please provide an explanation what makes these persons vulnerable)<br><br>Four employees working for startups in the Northern Netherlands, and four employees of publicly-funded institutions. |
| 4.3 Will participants be enlisted in the project without their knowledge and/or consent? (E.g., via covert observation of people in public places, or by using social media data.) | No. |
| 4.4 Categories of personal data that are processed.<br><br>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.<br><br>Of course, always ask yourself if you need all categories of data for your project. | ☒ Name and address details<br>☐ Telephone number<br>☐ Email address<br>☒ Nationality<br>☐ IP-addresses and/or device type<br>☒ Job information<br>☐ Location data<br>☐ Race or ethnicity<br>☒ Political opinions<br>☐ Physical or mental health<br>☐ Information about a person's sex life or sexual orientation<br>☐ Religious or philosophical beliefs<br>☐ Membership of a trade union<br>☐ Biometric information<br>☐ Genetic information |
| 4.5 Technical/organisational measures<br><br>Select which of the following security measures are used to protect personal data. | ☐ Pseudonymisation<br>☐ Anonymisation<br>☐ File encryption<br>☐ Encryption of storage<br>☐ Encryption of transport device<br>☒ Restricted access rights<br>☐ VPN<br>☐ Regularly scheduled backups<br>☐ Physical locks (rooms, drawers/file cabinets)<br>☐ None of the above<br>☒ Other (describe below): Only the company or institution the participants work for and their nationality are revealed, not their identity. |

| | |
|---|---|
| 4.6 Will any personal data be transferred to organisations within countries outside the European Economic Area (EU, Norway, Iceland and Liechtenstein)?<br><br>If the research takes places in a country outside the EU/EEA, then please also indicate this. | No. |

| 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? | Please see the 'Ethical Considerations' section to read the measures I took to conduct the data collection in a way that minimized risks of harm-doing. |

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