The potential of hydrogen in the ‘Nedersaksenlijn’ case

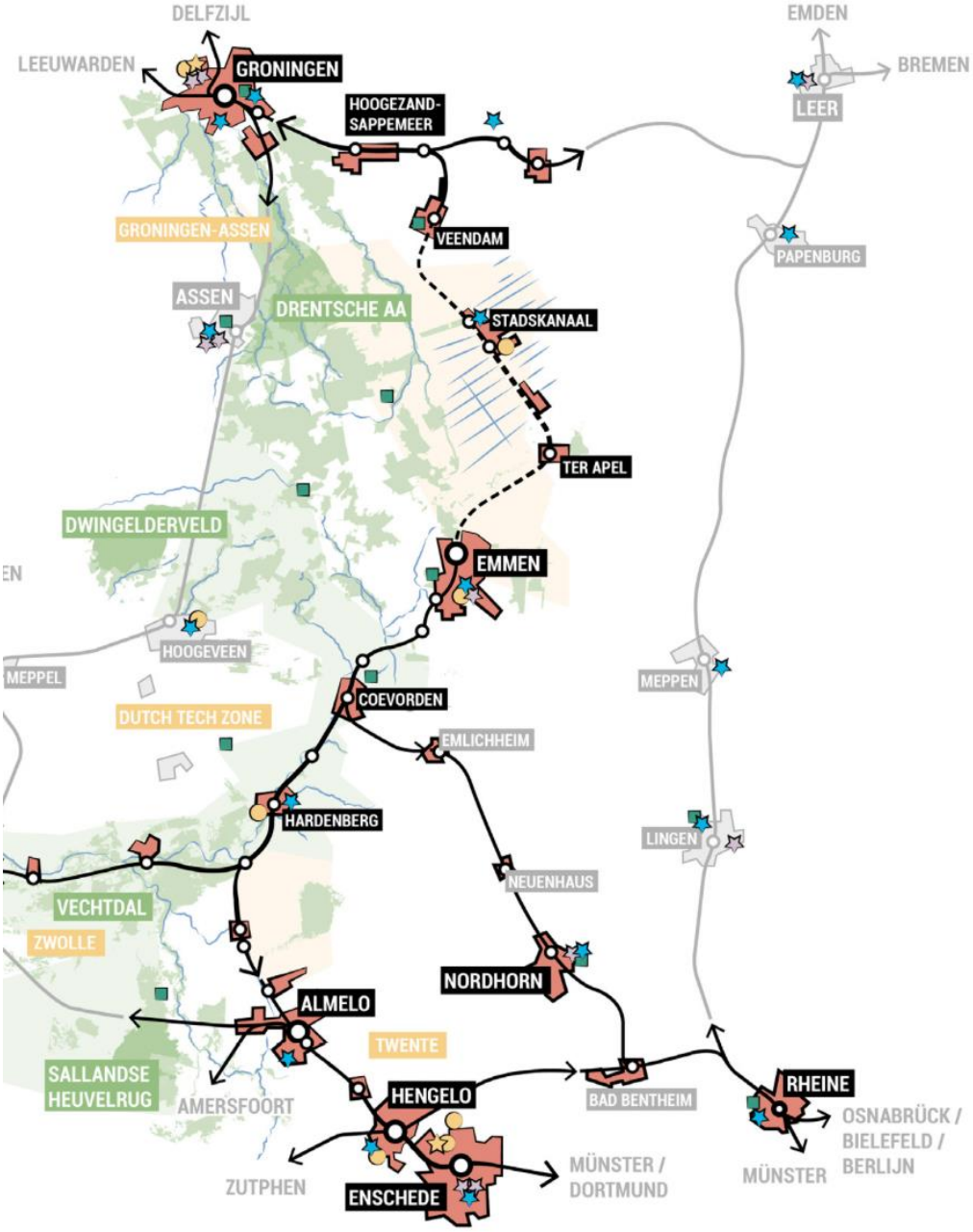

Figure 1: The Nedersaksenlijn (Province of Drenthe, 2024)

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Abstract

Global warming, largely attributed to the emission of fossil fuels, requires innovation. The mobility sector has a large share in emissions worldwide. Therefore, it is imperative to explore alternative solutions within this sector to reduce emissions and ultimately make a transition to a zero-emission mobility sector. In addition to battery-electric vehicles, hydrogen has emerged as a new player in the market. This research employs a case study approach to investigate the potential of hydrogen in the 'Nedersaksenlijn' within the European project EHRIN (Excellent Hydrogen Regions in Europe). The main scope of the research is on the pitfalls and opportunities of using hydrogen in this new railway line between Groningen – Enschede. Existing literature and qualitative data were used. Four in-depth interviews were conducted with various important stakeholders in sustainable mobility. The lack of knowledge in the field of hydrogen, the limitations in hydrogen production, and the shortage in the hydrogen infrastructure will be the biggest challenges for the use of hydrogen in the 'Nedersaksenlijn'. However, the use of hydrogen in this specific case will offer the opportunity to provide economic progress in the region and will contribute to the broadening of the hydrogen economy in the Netherlands.

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1 Introduction

1.1 Background

In recent years, climate change together with other environmental issues has become an increasing problem. Some areas witness a heightened frequency of extreme weather events and increased rainfall, while others confront escalating occurrences of extreme heat waves and droughts. The emission of greenhouse gases, which significantly contributes to environmental issues, is primarily attributed to the utilization of fossil fuels such as oil, coal, and natural gas. A significant portion of global greenhouse gas emissions stems from transportation, with the energy consumption associated with mobility accounting for approximately 20% of total emissions (Ball & Weeda, 2016). The transportation sector contributes to approximately 25% of global energy-related carbon dioxide (CO2) emissions, primarily attributed to airplanes, heavy vehicles (trucks), and tankers (Gnann & Plötz, 2015).

In addressing climate change, novel policies have been implemented not only at the global scale but also at the European level. The Paris Agreement (2015), a worldwide environmental initiative, seeks to curtail climate change by urging nations to restrict the increase in global temperature within this century below 2 degrees Celsius above pre-industrial levels, with an aspiration to limit it to 1.5 degrees Celsius (Vivanco-Martin & Iranzo, 2023). In alignment with this global climate approach, Europe has established new objectives. This main environmental strategy is called the 'EU Green Deal'. This strategy will focus on tackling climate change and its effects in Europe. Crucial topics addressed within this strategy include energy, industry, climate, environment, transportation, etc. (Vivano-Martin & Iranzo, 2023).

The arrival of electric vehicles has demonstrated their viability as a promising alternative to the mobility sector. Nonetheless, it has become evident that the efficacy of electric vehicles is not (yet) universally applicable across all vehicular categories. A prominent limitation of the existing electric cars is their relatively small range compared to fossil fuel-powered cars. This deficiency in range poses a challenge for the transport industry, particularly in instances where extensive distances need to be traveled. A solution for the transport industry might be the adaptation of hydrogen technology as an energy carrier. This because hydrogen vehicles can cover a distance that is almost twice as long as electrically powered cars (Low, Haszeldine & Mouili-Castillo, 2020).

In the Netherlands, a significant portion of energy consumption relies on natural gas. After two decades of exploiting the Groningen gas fields, earthquakes started to occur, attributed to gas extraction. This resulted in discontent among residents regarding gas extraction. In response to these issues and societal resistance, the Dutch government resolved to stop gas extraction by October 2023 (Rijksoverheid, 2023). Given this historical context in the Groningen and Drenthe region, there is a substantial demand for alternative energy generation and carrier methods.

Hence, considerable deliberation is underway in this area regarding the integration of hydrogen into our societal framework. Within Europe, the region of Groningen and Drenthe is recognized as the 'Hydrogen Valley' (New Energy Coalition, 2024b).

1.2 The 'Nedersaksenlijn' case

Currently, the Northern Netherlands lacks a comprehensive railway network, particularly with no existing railway line between Veendam (Groningen) and Emmen (Drenthe). This deficiency in rail connectivity has led to a lack of mobility in this region. The 'Nedersaksenlijn', an initiative of the provinces of Groningen, Drenthe, and Overijssel, aims to address this by establishing a complete railway line between Groningen and Enschede (Province of Drenthe, 2024b). Government approval has been granted for this plan, and in the upcoming years, a new railway line will be partially constructed. In the context of the 'Nedersaksenlijn', the current consideration revolves around choosing between overhead lines for the new rail segment (electrification) or opting for a hydrogen train. Besides the emission-free nature of green hydrogen, this project will also ensure broad prosperity by connecting people, jobs, educational institutions, and facilities with both the rest of the Netherlands and neighboring Germany as outlined by the Province of Drenthe (2024b). The project's importance is substantial, and it is currently integrated into the European project EHRIN (Excellent Hydrogen Regions in Europe), an initiative led by the province of Drenthe focusing on exploring hydrogen possibilities and strengthening the hydrogen infrastructure and governance.
Within the scope of project EHRIN, this case specifically investigates the potential for hydrogen trains on the 'Nedersaksenlijn'.

1.3 The Research Problem

This research aims to gain a better understanding of the pitfalls and opportunities in the energy transition by using hydrogen in the mobility sector in the Groningen & Drenthe region. The primary focus of the study centers around the "Nedersaksenlijn' case. The main research question is:

'What are the pitfalls and opportunities of applying hydrogen in the 'Nedersaksenlijn' case?'

To answer the main question, the following sub-questions will be answered:

- How is the performance of current hydrogen developments assessed?
- What is the role of hydrogen in mobility on the perception of people?
- What options do current laws and regulations offer for the use of hydrogen?
- What are the main challenges for the use of hydrogen in mobility?

1.4 Reading Guide

In the next section, the theoretical framework and conceptual model of this study are presented. Then, the data collection and analysis will be discussed. This is continued by discussing the results. Then, the sub-questions will be addressed in the discussion. Ultimately, the main question will be answered in the conclusion.

2 Theoretical framework

2.1 Green Hydrogen

The predominant focus of academic research in the hydrogen field has been on the technical facets of hydrogen and its application in the context of mobility. Among the sustainable fuels, hydrogen has the highest energy by weight with zero-emission properties (Dash *et al,* 2022). This makes hydrogen an appealing sustainable fuel. However, there are several technical challenges. The accessibility and environmentally friendly production of hydrogen present significant challenges for the use of hydrogen as an energy source. Given that hydrogen is not naturally occurring, its production becomes imperative. This production requires significant amounts of energy, so the way hydrogen is produced is very important in the impact on the climate (Jones & Neilson, 2021). The production of hydrogen yields three end products, gray hydrogen, blue hydrogen, and green hydrogen (Figure 2). Both gray and blue hydrogen are derived from fossil fuels. The production process of gray hydrogen results in the release of CO2 into the atmosphere. In the case of blue hydrogen production, the emitted CO2 is captured and stored to mitigate greenhouse gas emissions. While this approach is more environmentally friendly, it is also associated with higher costs. For the most effective mitigation of climate change, the optimal approach involves the production and utilization of green hydrogen. This type of hydrogen is generated using energy derived from sustainable sources such as solar panels and wind turbines. The production of green hydrogen entails the process of electrolysis, which requires the input and output of sustainable energy (Jones & Neilson, 2021). However, it is essential to note that the primary drawback of this method is its high costs. To have a completely emission-free production cycle, green hydrogen is the only option and thus the most suitable to meet the national and international objectives. In the next section, the question of which vehicles are best suited for green hydrogen as a fuel will be discussed.

Figure 2: Overview of different types of hydrogen (Province of Drenthe, 2024)

2.2 Electric vehicles (EVs) vs. hydrogen fuel cell vehicles (HFCVs)

As reported by the International Energy Agency (AIE) in 2020, the transportation sector, which stands as the second-largest contributor to carbon emissions globally, plays a big role in driving global warming, accounting for approximately 26% of the total carbon emissions (Gnann & Plötz, 2015). Therefore, countries should take measures aimed at decreasing the use of fossil vehicles or, indirectly, reducing fossil energy consumption. Due to the rising consumer demand for cars, reducing car usage may not be feasible; hence, the transformation

of cars becomes imperative. According to Shi *et al.,* (2020), the rapid progress in new energy vehicles, exemplified by battery electric vehicles (BEVs or EVs) and hydrogen fuel cell vehicles (HFCVs), are commonly seen as two viable approaches to efficiently substitute internal combustion engine vehicles. Nevertheless, there exist notable variations in the market size for these two emerging vehicle types today. The production and sales of EVs have reached 2504 times and 2466 times than that of HFCVs according to the Chinese Association of Automobile Manufacturers (Zhang, Fang & Sun, 2023). The primary factor contributing to the substantial electric car market is the pricing of vehicles.

In comparison to HFCVs, EVs are more affordable. Additionally, the charging infrastructure in the country is significantly more extensive than any existing hydrogen network. However, the shift to electric vehicles is not the most effective in every sector of mobility. Electric vehicles have some disadvantages such as a long battery charging time and limited driving range (Dash *et al.,* 2022). According to Jones & Neilson (2021), despite the environmental and efficiency benefits associated with battery electric vehicles, lithium-ion batteries have only approximately 1% of the energy density found in petrol or diesel. For this reason, smaller and lighter vehicles appear to be the best candidates for battery-electric use. As vehicles increase in size, the necessary battery pack's size and weight, as well as the achievable range, start to make battery power a less appealing option. Therefore, the use of HFCVs in the heavy transportation sector emerges as a favorable alternative due to the size of the vehicles and the considerable distances that need to be covered.

2.3 The hydrogen train

As discussed in the previous section, hydrogen is a good alternative sustainable fuel for the heavy transport sector. The use and potential of hydrogen in the train sector is therefore not indispensable, due to the sector's specific characteristics, such as the need to cover long distances and the operation of large, and heavy vehicles. In addition, the mobility sector, including the train sector contributes to global CO2 emissions. According to Blanco *et al.,* (2018), the rail sector generates 4.2% of global transport-related emissions and demand. Hence, there is a need to explore alternative energy methods and technologies within the rail sector to achieve lower emissions. In addition to electric trains, commonly powered by overhead lines, hydrogen trains should play a significant role in shaping the train market. In the article of Blanco *et al.,* (2018), the advantages of hydrogen fuel cell-powered trains are compared with trains with other technologies, such as electricity. Five main advantages have been drawn; Flexible levels of hybridization, Fast refueling, Operating more efficiently on a wider range of routes, lower total cost of operation, and no compromise in performance. The interest sparked by these advantages is reflected in the current developments in Groningen. Currently, the regional railway in Groningen lacks an overhead line, making it necessary to install this before electrically powered trains can operate. This installation covers many kilometers of regional rail, which costs a lot of money. Given the plan that only zero-emission trains may run by 2030, Groningen has explored alternative solutions. For this reason, Groningen conducted test runs with hydrogen trains in 2020 (Prorail, 2024a). Ultimately, in November 2022, the province initiated a procurement process for four additional hydrogen trains (Province of Groningen, 2022). In addition, there is an urgent need for a reliable hydrogen supply network and the associated refueling infrastructure.

2.4 Law and Regulation

Given the fact that the Netherlands only wants to use sustainable energy sources by 2050, the Dutch government is encouraging the use of hydrogen. The government wants to develop a sustainable energy mix, including renewable electricity and heat (Rijksoverheid, 2024). The influence of hydrogen is significant in these developments, as not everything can be made sustainable with electricity. The Dutch climate agreement, which was drawn up in 2019, outlines specific targets for hydrogen. An important goal of this agreement is to realize a nationwide network of 50 hydrogen filling stations by 2025 (Rijksoverheid, 2024). Given that hydrogen is a relatively new way of generating energy, existing laws and regulations are limited, but future objectives have been outlined. However, there are currently certain measures from the Dutch government to encourage the use of hydrogen. An important example is the subsidies for hydrogen projects.

The Dutch government subsidizes innovative hydrogen technologies. In 2022, the government has allocated a subsidy scheme of 22 million for realizing more hydrogen filling stations (Rijksoverheid, 2024). In addition to subsidies, the concept of market organization is also an important theme. The organization of the market indicates which parties (public and private) may operate or enter a market under which conditions (rules and regulations), and what rights and obligations end customers have (Gasunie, 2024b). The development of the hydrogen market is a process that will continue in the coming years, and as a result, market regulation is an ongoing process. So, regarding hydrogen legislation and regulations, there is still considerable development to be done. The European hydrogen policy also holds a significant influence in this process. Any new European policies will prompt expansions in the Dutch legislation and regulations.

2.5 Hydrogen Infrastructure

An important concept within the hydrogen domain is the ‘hydrogen economy’. This concept explores the utilization of hydrogen as a low-carbon fuel for heating and as an energy carrier in mobility and transportation (Ball & Weeda, 2016). Not only the production of hydrogen, as mentioned earlier, must be achieved sustainably, but the transportation and distribution of the produced hydrogen is important. According to Ball & Weeda (2016), the transportation of hydrogen depends on hydrogen volumes, delivery distances, and local circumstances. This can be done by delivering hydrogen through compressed gaseous (CGH2) and liquid hydrogen (LH2) by trucks of gaseous hydrogen pipelines. The existing gas pipeline network in the Northeast Groningen region, which was used for gas extraction, offers good opportunities to act as a transportation mode of gaseous hydrogen in the Netherlands. The transport of compressed hydrogen via pipeline has been considered the most cost-effective option for short distances (<3000 km) (Lipiäinen *et al.,* 2023). To improve and stimulate the use and demand of hydrogen in the Netherlands, it is essential to undertake spatial developments, ensuring the availability of hydrogen in more locations. The suitability of hydrogen delivery options depends on the hydrogen market penetration and, therefore, is likely to change over time (Moreno-Benito, Agnolucci & Papageorgiou, 2017). As the Dutch hydrogen economy expands in the future, there need to be some shifts in the delivery of hydrogen, with a focus on improvements in its accessibility.

2.6 The perception of people

In addition to hydrogen production, good infrastructure and, suitable application within specific mobility sectors, the role of people, namely consumers, also plays an important role. The integration of hydrogen into daily life shapes people's opinions and, consequently, their overall perception. The term 'perception' refers to how an entity perceives, regards, understands, associates, interprets, or becomes aware of something, in this case, hydrogen (Emodi *et al.,* 2021). One key term in the perception of people is 'Social acceptance'. The hydrogen economy is in its early phase and social acceptance plays a notable role in its development (Lipiäinen *et al.,* 2023). An important factor in social acceptance is the fact that the new technology, hydrogen, must have more advantages than disadvantages. Within social acceptance, there is a three-dimensional approach to better understand social acceptance, and the key actors are shown in Figure 3. (Emodi *et al.,* 2021).

Figure 3: Social acceptance triangle (Emodi, N.V. et al., 2021)

The social-political acceptance refers to the confidence of the public. Furthermore, the focus of community acceptance is more concerned with the level of resistance. The interests and opinions of community members are crucial. Finally, the focus of market acceptance is mainly on the understanding and awareness of hydrogen.

The impact of hydrogen on people's perceptions is highly diverse. Some already consider it a promising and environmentally friendly energy source. Those people already have a deeper understanding of the societal impact of hydrogen. However, given the fact that hydrogen is still a relatively new phenomenon, many individuals are still hesitant about hydrogen and its use in mobility. The main concern is the safety of hydrogen. The link with the hazard of an explosion is often made by these individuals. Moreover, the expected demand for hydrogen will increase in the upcoming years, particularly when it is used more often in mobility. This increase in demand will lead to an increase in supply resulting in an increased risk of errors in quality and safety. The growing use of hydrogen will also create a demand for individuals with specialized knowledge. Ensuring the maintenance of hydrogen factories and the development of strategic filling points for hydrogen-powered trains for instance. As knowledge increases, it is likely to have a positive influence on the public perception regarding the use of hydrogen.

2.7 The conceptual model

The conceptual model presented in Figure 4 is a visual representation of the research. The presented model highlights key concepts, topics of the sub-questions, and outlines the research process from left to right. It provides insights into important topics within the literature study. In addition, it illustrates the various mobility sectors where interviews were carried out. Ultimately, these outcomes will contribute and visualize the opportunities and pitfalls of the use of hydrogen in the 'Nedersaksenlijn'.

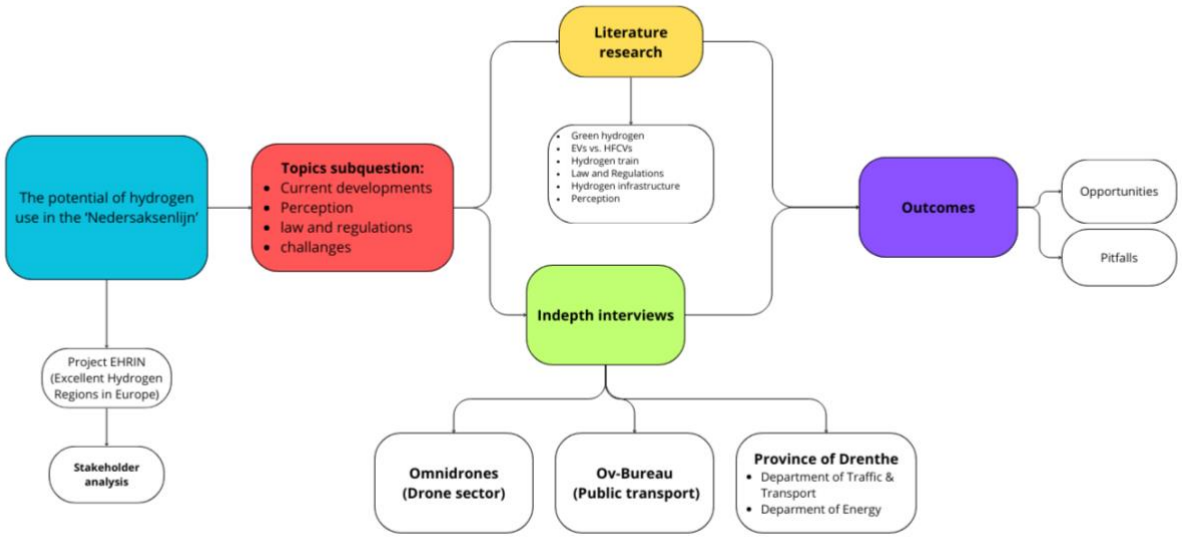

Figure 4: Conceptual model (made by author, 2024)

3 Methodology

3.1 Data Collection

For this research, existing literature on hydrogen-related mobility was used. Additionally, gathering information and insights from experts on this topic was crucial. The primary emphasis was on the key themes; hydrogen advancement, legal and regulatory frameworks, challenges, and future.

The primary data for this research was gathered and analyzed through a semi-structured interview approach. As posited by Clifford *et al.,* (2016), this instrument proves particularly valuable when comprehensive information is essential for the subject under investigation. This stands in contrast to a survey, which tends to yield more surface-level data compared to the detailed and in-depth insights derived from semi-structured interviews.
The primary data gathered contributed to addressing the sub-questions within this research and resolving these sub-questions ultimately provided insights into the main question. To conduct the interviews, I have reached out to various stakeholders with expertise in the field of hydrogen and mobility. Four entities have been selected for interviews in this study. Given that the Project EHRIN and the 'Nedersaksenlijn' case initiatives are from the province of Drenthe, interviews have been conducted with representatives from the Traffic & Transport department and the Energy department. Additionally, to explore hydrogen usage in distinct mobility contexts, I conducted an interview with Omnidrones, a company focusing on hydrogen use in drones, and the last interview was held with the OV-Bureau to discuss the application of hydrogen in public transport, specifically buses.

Table 1 provides an overview of all individuals who were interviewed during this study. Important in this research was to examine the results of the use of hydrogen in various parts of the mobility sector. To achieve this objective, interviews were held with the owner of Omnidrones, to give information on hydrogen developments within the drone industry. Additionally, an interview was conducted with a public transport agency, OV-bureau Groningen Drenthe, aiming to understand the progress of hydrogen implementation in the bus network of the region. The insights of these two mobility sectors can provide insights into the development of hydrogen in the train sector.

Table 1: Overview of interviewees in this research (made by author, 2024)

Interviewee	**Sex**	**Region**	**Department**	**Length interview**	**Interview location**
1	Male	Groningen	Omnidrones	21.55 min	Online
2	Male	Drenthe	Energy	31.09 min	Provinciehuis Assen
3	Female	Drenthe	Traffic & Transport	31.23 min	Provinciehuis Assen
4	Male	Groningen & Drenthe	OV-Bureau	1 h. 15 min	OV-Bureau Assen

3.2 Data analysis

The data collected from the interviews was analyzed using a deductive coding tree (Figure 5). Within the interviews, there were five categories. The same codes were used for each category to see a connection or link between the individual categories within the same interview. Furthermore, connections have been drawn between the outcomes of the various interviews.

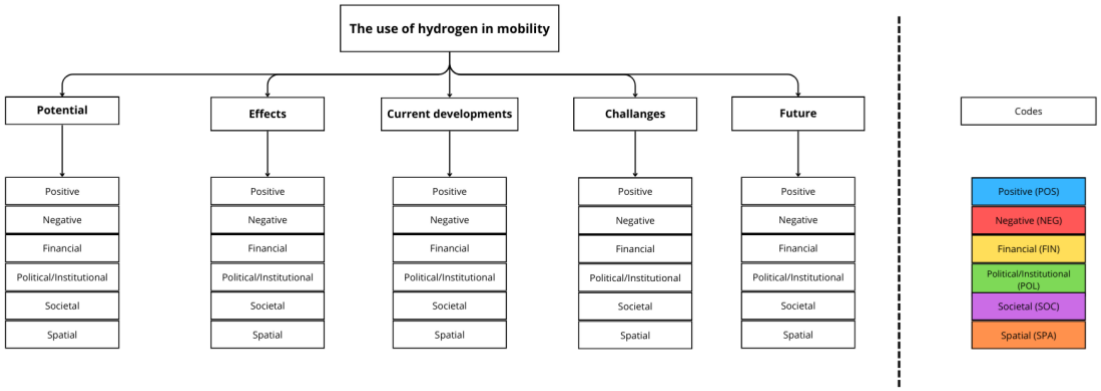

Figure 5. Deductive code tree (made by author, 2024)

3.3 Ethical issues

Since this research employed qualitative methods for data collection, it was necessary to consider the ethical aspects carefully. The participants were provided with comprehensive information well in advance of the interview, outlining the content and specifying the data handling procedures. The interview guide and consent form are available in the Appendix (8.1.1 & 8.1.2). Ensuring the interviewee's comfort, the interviewee was free to choose where the interview would be held. This familiar environment will lead to more honest answers. It was explicitly communicated that participation in the research is entirely voluntary, and participants had the right to terminate their involvement at any point for any reason. The interview process involved recording with an audio recorder, and explicit consent was obtained from participants for this purpose. It was underscored that their identity would remain completely anonymous, and the recorded data would only be accessed and utilized by the researcher.

3.4 Stakeholder analysis

As an assignment for project EHRIN on behalf of the province of Drenthe, I've conducted a stakeholder analysis for this research. The primary objective of this stakeholder analysis was to contribute to the investigation of the potential of hydrogen in the 'Nedersaksenlijn'. The analysis aimed to offer a comprehensive understanding of the interests, expectations, and influences of different stakeholders involved in the utilization of hydrogen in this specific case. This analysis identified the key stakeholders, an exploration of their interests and priorities, and ultimately served as a valuable information source for any decision-making. The stakeholder analysis can be found in the Appendix (8.2).

4 Results

This section presents the results of the data gathered through the interviews. The results are divided into the categories; Potential, Effects, Current developments, Perception, and Challenges. First, I turn to the potential of hydrogen in the mobility sector.

4.1 The potential of hydrogen in the mobility sector

When considering the appropriate type of train for a specific route, such as the 'Nedersaksenlijn', the decision-making process is currently challenging. The dilemma revolves around choosing between electric trains and those powered by hydrogen. Given the fact that electrically powered trains, through overhead lines, are already operational in the Netherlands, the focus of the interviews was mainly on hydrogen. To see what hydrogen can mean in mobility and specifically in the train sector, the first question was focused on the potential of hydrogen in the mobility sector.

"…, The availability of hydrogen and green hydrogen in particular is still quite limited." (Interviewee 2 from Energy Department province of Drenthe, 2023)

According to all interviewees, there was indeed potential for hydrogen as a viable alternative fuel/ energy carrier. The primary challenge highlighted by Interviewee 2 is the current availability of hydrogen. Additionally, he emphasized a distinction, noting the significance of green hydrogen, as it represents a form of hydrogen production that is emission-free. Presently, there is insufficient availability of hydrogen in the market to support widespread utilization on a large scale.

"…, if you have hydrogen, you must pay for your installation. That is included in the price per kilo which makes it more expensive compared to electricity. Part of those costs are socialized…" (Interviewee 4 from OV-bureau Groningen Drenthe, 2024)

In addition to the challenges in hydrogen production, the pricing of hydrogen is a crucial factor influencing its potential. Currently, the cost of hydrogen exceeds that of electricity, a point elaborated by Interviewee 4 in the explanation of why this price difference exists. For this reason, according to the experts, people are opting for electricity more frequently.

4.2 The effects of hydrogen

The potential adaptation of hydrogen in the 'Nedersaksenlijn' is also contingent upon the impact of hydrogen. This involves examining what the positive and negative effects are and their broader implications.

"…that you want to achieve emission reductions and at the same time in this region, it is also about making your employment and economy more sustainable or future-proof…" (Interviewee 2 from Energy Department province of Drenthe, 2023)

Beyond the positive impact of green hydrogen in emission reduction, it also has positive effects on the surrounding area and the local environment. According to Interviewee 2, it contributes to economic growth and long-term sustainability. The adaptation of hydrogen enhances expertise in the field and is expected to create more employment opportunities through the establishment of new hydrogen-related companies in the Groningen Drenthe region. Within mobility, it will also yield positive effects on the duration required for vehicle refueling or charging. Unlike electricity, refueling with hydrogen is significantly faster.

"…One of the major advantages of hydrogen is that it can be filled quickly..." (Interviewee 1 from Omnidrones, 2023)

4.3 Current developments

Before making a choice, it is important to draw insights from ongoing projects, examine the performance of hydrogen vehicles, and identify both their strengths and weaknesses. The evaluation of hydrogen buses in the Qbuzz timetable, as indicated by Interviewee 4, currently reflects a highly positive assessment.

"I would almost say that the buses that are now running, given the number of kilometers they drive, consumption is lower than expected. That's why extra kilometers are driven on the city lines." (Interviewee 4 from OV-bureau Groningen Drenthe, 2024)

Positive advancements are also observed in the drone sector, attributed to the extended range achievable with hydrogen. Consequently, in both mobility sectors, the incorporation of hydrogen demonstrates favorable impacts on vehicles. However, it is essential to address numerous drawbacks. The duration of the development process emerges as a crucial aspect that demands attention (Interviewee 2).

"You need a lot of patience to achieve development, on the one hand, because you do not (yet) have a good business case for both the production of hydrogen and also for the application of hydrogen." (Interviewee 2 from Energy Department province of Drenthe, 2023)

4.4 Laws- and regulations

Integration of hydrogen into the field of mobility requires attention to legislation and regulations. In the context of hydrogen, there are currently limited established rules and laws due to the early stages of its implementation (Interviewee 2 & 3)

"…Because not everything has been laid down in terms of rules about hydrogen…" (Interviewee 2 from Energy Department province Drenthe, 2023)

"…That is also in the early stages. That is the quest because the legislation has not yet been adapted to it all…" (Interviewee 3 from Traffic & Transport Department province of Drenthe, 2024)

This doesn't imply a complete absence of regulations. In the national policy, the government presides over certain hydrogen developments with subsidies, marking a positive initiation. However, Interviewee 4 suggests that the current emphasis is largely on initiating plans. Financial support must then also be made available for the operational part. This is not yet the

case, leading decision-makers to favor electricity over hydrogen due to lower and more predictable operating costs when using electricity as an energy source.

"…make once money available, only provide money at the front, i.e. purchase of vehicles and installation costs, and then the installation has to start operating itself…" (Interviewee 4 from the OV-bureau Groningen Drenthe, 2024)

4.5 Perception

The role of hydrogen in the perception of people in the drone sector plays a relatively large role. The use of drones itself is an innovation and something people must get used to. Besides that, people frequently perceive hydrogen as potentially hazardous and prone to rapid explosions. Therefore, Interviewee 1 suggests that advertising hydrogen within this sector is advisable.

"…people sometimes associate it with explosion hazard…" (Interviewee 1 from Omnidrones, 2023)

In the public transport sector (buses & trains), the remaining interviewees observe a contrasting perspective. In this context, as it involves public transit, the general sentiment is that passengers are primarily concerned with the efficiency and punctuality of the service rather than the specific sustainable fuel utilized. The mobility of the people is prioritized over the type of fuel present in the vehicle.

"As far as I am aware and what we also notice among travelers, there is no difference. They just want to be taken from A to B." (Interviewee 4 from OV-bureau Groningen Drenthe, 2024)

4.6 Challenges

The energy transition through hydrogen still has plenty of challenges now. Primarily because of the lack of sufficient knowledge. We are currently in a discovery phase in the field of hydrogen. This leads to delays in the overall process, constituting a significant challenge. Gaining knowledge should have a greater influence in the coming years on the speed at which hydrogen can be used on a large scale.

"I think the unfamiliarity, so we must experiment with it, pioneer, and don't be afraid." (Interviewee 3 from Traffic & Transport Department province of Drenthe, 2024)

In addition to the lack of sufficient knowledge, the lack of a good hydrogen infrastructure in the Netherlands poses an additional challenge. The transportation of produced hydrogen is currently constrained due to limitations in the pipeline network. Furthermore, hydrogen filling stations are scarce. Finally, the current cost of hydrogen remains high. The energy-intensive process of hydrogen production contributes to a higher cost per kilogram compared to electricity (Interviewee 3).

"…availability of filling points, hydrogen filling stations, so that we can refuel at all. Far behind that is the availability of enough green hydrogen for the right price…" (Interviewee 2 from Energy Department province of Drenthe, 2023)

5 Discussion

The first sub-question explored the performance of the current hydrogen developments in de region. This includes the deployment of hydrogen buses by Qbuzz, the hydrogen innovation in the drone industry, and an exploration into why Groningen has chosen to invest in four hydrogen fuel cell-powered trains. In both public transportation and drone sectors, the use of hydrogen is currently receiving positive reviews. Hydrogen enables vehicles and drones to cover long distances efficiently in contrast with the capabilities of electricity battery-powered vehicles. However, the main problem nowadays is the availability of hydrogen. As a result, it can't be used on a large scale yet. Due to this limited availability, the costs of hydrogen per kg are higher compared to electricity. For this reason, there is restraint in the use of hydrogen. In addition to limited availability and high costs, the lack of knowledge is also a crucial problem. This lack of knowledge limits the implementation process of hydrogen in mobility in terms of duration. Nevertheless, the start of a procurement process of four hydrogen trains by Groningen is expected to have a socially positive impact. These trains will be subject to experimentation in the coming years in the hydrogen economy. This will contribute to the expansion of knowledge about hydrogen in mobility, especially within the rail industry. This knowledge can be valuable in the context of the 'Nedersaksenlijn' case.

As this study focuses on a segment of public transportation, specifically trains, answering sub-question two, about perception, becomes relatively straightforward. The interviews revealed that passengers are primarily concerned with the train's functionality. Whether it is an electric train or a hydrogen cell-powered train is less important to them, as long as they remain mobile. It is up to policymakers to determine which alternative works best for this railway line. To enhance people's perception of hydrogen, it is essential to emphasize additional benefits beyond its positive impact on the climate. Hydrogen presents opportunities for regional economic growth through more employment and technical innovations. These aspects positively contribute to social acceptance. However, this research shows that there is still a fear about hydrogen itself, mainly concerning the perceived risk of explosions.

The results indicate a need for changes in regulations and legislation (sub-question three). There are currently too few rules and laws that positively impact the adaptation of hydrogen. One contributing factor is that the use of hydrogen is still in its development stage, and there is insufficient knowledge available. That is why not enough laws and regulations have been made yet. A start has been made in the Netherlands through a government subsidy program aimed at supporting hydrogen-related projects. However, the current subsidy is in a lot of cases not enough and focuses only on the beginning phase of a project, i.e. purchasing a hydrogen bus or train. Operational costs are not enough considered. The existing challenges are between the government's objectives and plans and the absence of comprehensive regulations that will help the objectives to succeed.

Finally, the study has identified several challenges for the use of hydrogen in the future. Understanding these challenges is crucial for facilitating policy decisions related to hydrogen use in the future. One of the biggest challenges now is the production capacity of green hydrogen. The amount of energy required, particularly from continuous electrolysis, limits the amount of green hydrogen that can be produced. As a result, the price of hydrogen remains too high (20 euros per kilogram), which means that companies do not quickly switch to

hydrogen as an alternative energy carrier due to the high costs. Additionally, the absence of a hydrogen network with associated hydrogen filling stations poses a future challenge. For a successful energy transition with hydrogen, hydrogen must be accessible across different locations in the Netherlands and at places where a train can refuel with hydrogen. Spatial adjustments are necessary to transport the produced hydrogen to the places where it is required. Another challenge lies in the unfamiliarity of hydrogen in the mobility sector. Currently, there is insufficient knowledge about hydrogen and its requirements, presenting a challenge for its widespread adaptation in the Netherlands in the future.

In the upcoming period, it is essential to conduct more experiments with hydrogen to research its cost-effectiveness compared to electricity, analyze the frequency of disruptions, and determine the purchase prices for hydrogen trains. All this is to ensure additional knowledge that can contribute to addressing climate-related challenges more effectively and precisely in the future.

6 Conclusion

This research aimed to gain information about the potential for hydrogen use in the 'Nedersaksenlijn' case. Specifically, the pitfalls and opportunities were researched. With the help of qualitative data from interviews with experts on hydrogen in mobility, the following main question was tried to answer: *'What are the pitfalls and opportunities of applying hydrogen in the 'Nedersaksenlijn' case?'* To answer this central question, four sub-questions were proposed and answered.

In addition to the secondary data, the responses obtained in the interviews played a crucial role in addressing all four sub-questions. These sub-questions were centered around four themes: current developments, perception, law and regulation, and challenges. Since the outcomes originated from various sectors related to mobility, the drone sector, and public transport, the findings from these questions can be readily applied in the 'Nedersaksenlijn' case.

To answer the central research question, primarily, the introduction of a zero-emission vehicle on this railway line aligns with established national objectives. Furthermore, it will have a positive influence on the broader region, affecting aspects like the economy, housing market, and education. The introduction of hydrogen in an area currently perceived as less developed will have a positive impact on the status. This attracts new residents and retains those already living there. In addition to a hydrogen train, the establishment of a hydrogen factory and hydrogen refueling stations is essential. These pioneering advancements demand individuals with the right knowledge and expertise in the field of hydrogen with the result that prosperity will improve. Ultimately, the introduction of hydrogen in the 'Nedersaksenlijn' and the associated hydrogen economy will contribute not only to the regional hydrogen landscape but also on a National and European level.

Despite the opportunities, the implementation of hydrogen in the 'Nedersaksenlijn' currently faces some pitfalls. Due to gaps in knowledge, the reliability of hydrogen in the train industry remains insufficient. Additionally, the current production of green hydrogen is not meeting

the required levels, which results in prices higher than the price of electricity. The hydrogen network also lacks both distribution pipelines and filling stations. This is a concern because of the existing electricity infrastructure in the whole country. If a hydrogen train is chosen for this railway, careful consideration is necessary for determining the strategic locations of filling stations, and even the considerations of the general hydrogen options. For this difficult issue, the stakeholder analysis can be a valuable tool for discussing the options with the stakeholders. Finally, the existing regulations are not good enough, with a shortage of rules that actively promote the use of hydrogen and a shortage of financial support in the process.

Ultimately, it is up to policymakers which option they prefer in the 'Nedersaksenlijn' case. On the one hand the rather safe, expensive but well-known option for implementing an electrically powered train with overhead lines, or on the other hand the riskier choice of a hydrogen train which in addition to climate benefits, also has a positive impact on the entire upcoming hydrogen economy and the region.

6.1 Reflection

Formulating the appropriate research question and sub-questions proved to be a challenging task for me. I kept the topic too broad. Ultimately, with the help of my internship at the province of Drenthe, I was able to refine and execute interesting research. The experience of conducting interviews was remarkably positive, providing valuable learning opportunities. In retrospect, it might have been beneficial to include an interview with a stakeholder from the province of Overijssel to gain a more comprehensive understanding of the entire region of the case. The research aims to contribute to the adaptation of hydrogen in the Northern Netherlands, generating insights that, ideally, stimulate the use of hydrogen. Future researchers can use this study as a basis resource for hydrogen-related projects in the mobility sector.

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8 Appendix

8.1 Data collection instrument

8.1.1 Interview guide & consent form

Information form research project

This document contains information about the research in which you are participating and hopes to inform you about the content of the project, the study, and the processing of the data collected during the interview.

This research is the graduation project for the bachelor's degree in Spatial Planning and Design at the faculty of Spatial Sciences at the University of Groningen.

The use of hydrogen in the energy transition is becoming an increasingly important theme. This research focuses on the pitfalls and opportunities of using hydrogen in the mobility sector in Groningen and Drenthe. The data in the research will be collected through literature research and by conducting interviews with various parties. The research questions will mainly focus on the topics; potential, effects, developments, challenges, and future prospects.

The identities of the participants will remain completely confidential. The interview will be recorded with an audio recorder to allow the information to be analyzed afterward. No name is mentioned in the transcript. In addition, all other information that could potentially lead to the identification of the participant will be anonymized. Thus, the identity of the participant will only be known by the researcher.

Both the recording and the transcribed interview will be stored on a secure drive and will be destroyed once the investigation is completed.

It is important to emphasize that participation in this research is completely voluntary. At any time, the participant can choose to no longer participate in the research.

Consent form for participation in research project

I have read the information about the research project. Sufficient time has been provided to decide whether to participate in the research. My participation is completely voluntary, and I have the option to withdraw at any time, without the need to provide a reason. I am aware of how the interview is stored and processed.

I agree to:

- Participation in the interview.
- The recording of the interview.
- I agree that the interview data is being used for educational purposes.

Name of participant:

Signature of participant

Date interview:

I, the researcher, declare that I have informed the interview participant about the research.

Name researcher:

Signature of researcher:

Date of interview:

8.1.2 Interview Questions

Starting question: Can you tell something about yourself and the work that you are doing?

Main questions

Potential

1. What do you think is the potential of hydrogen as an alternative energy carrier?

Effects

2. What are the effects of using hydrogen as an energy carrier?

Developments

3. How is the performance of current hydrogen developments assessed?
4. Do the laws and regulations allow room for hydrogen development?
5. What role does people's perception play in hydrogen developments?

Challenges

6. What are the biggest challenges for the use of hydrogen in mobility?

Future perspectives

7. How do you see the future in the use of hydrogen?

Extra questions

1. a) Can you give an example?
   b) Can you elaborate on this?

2. a) Can you give an example?
   b) Are there any other effects?
   c) Are there also positive or negative effects?
   d) Can you elaborate on this?

3. a) Can you give an example?
   b) Can you elaborate on this?

4. a) What are the most important laws and regulations?
   b) Does it offer opportunities or is it a hindrance, and why?

5. a) What is the main perception?
   b) does this help of hinder the energy transition?

6. a) How do you think this can be solved?
   b) Who is needed for this?
   c) Can you elaborate on this?

7. a) Can you elaborate on this

STAKEHOLDER ANALYSIS

The potential of hydrogen in the 'Nedersaksenlijn'

Jasper Mekkelholt

On behalf of the Province of Drenthe |Westerbrink 1, Assen |

26-01-2024

provincie Drenthe

Interreg North Sea

Excellent Hydrogen Regions in Europe (EHRIN)

Table of Content

Stakeholder Analysis ‘Nedersaksenlijn’

The research into the application of hydrogen in the ‘Nedersaksenlijn’ is a crucial initiative not just to transform the mobility infrastructure but also to stimulate positive advancements in the regional hydrogen economy. There are various parties and stakeholders that play a role in the implementation of hydrogen in the Northeast of the Netherlands (Groningen, Drenthe, and Overijssel). This stakeholder analysis aims to provide an in-depth insight into the various actors/parties involved in the implementation of hydrogen technology into the ‘Nedersaksenlijn’ and its surrounding area.

Through a comprehension of the project’s dynamics, we aim to identify the interests, influences, expectations, and interrelationships of key stakeholders. The information can be used to develop strategies to optimize collaboration and address potential challenges effectively. In conclusion, this analysis will enhance our understanding of the potential of hydrogen within the ‘Nedersaksenlijn’ as part of project EHRIN.

Overview stakeholders

- Provinces of Groningen, Drenthe, and Overijssel

- ProRail: Oversees the railway network in the Netherlands, acting as the railway manager and is, therefore, responsible for the construction, maintenance, management, and safety of the railway (ProRail, 2024b).

- Arriva: Functions as the provider of passenger transport on regional railway lines in the Netherlands, including the 'Nedersaksenlijn', which integrates into the regional railway network in the Northern Netherlands (Arriva, 2024).

- The Ministry of Infrastructure and Water Management: Focuses on a well-organized, clean, and safe environment. Its focus extends to developing connections across road, rail, water, and air (Ministry of Infrastructure and Water Management, 2024).

- NAM (Nederlandse Aardolie Maatschappij – Dutch Oil Company): Explores the utilization of existing gas infrastructure for future sustainable solutions, considering pipelines and locations. Additionally, it explores possibilities regarding blue hydrogen for a rapid transition to hydrogen (NAM, 2024).

- Hynetwork Services: A 100% subsidiary of N.V. Nederlandse Gasunie. It aims to develop and manage a large-scale hydrogen infrastructure in the short term. Existing gas transport networks are repurposed, and new pipelines are installed where the current network proves unsuitable. The primary focus is on establishing the hydrogen network in Drenthe and Overijssel (Hynetwork Services, 2024).

- The Ministry of Economic Affairs and Climate: Responsible for coordinating decisions and permits related to hydrogen, aiming to achieve a climate-neutral society while providing clean, reliable, and affordable energy (Ministry of Economic Affairs and Climate, 2024).

- Alstom: An international company dedicated to sustainability in the transportation sector, specializing in the production of hydrogen trains that contribute to the sustainable development of mobility in Europe (Alstom, 2024). In 2020, Groningen conducted test runs with this type of hydrogen train (ProRail, 2024a). Ultimately, in November 2022, the province initiated a procurement process for four additional hydrogen trains (Province of Groningen, 2022).

- Engie: An energy supplier actively participating in the green hydrogen chain in the Northern Netherlands (HydroNetherlands). Engie is involved in hydrogen production and has expertise in hydrogen refueling stations, playing a role in the introduction of the first hydrogen train in the Netherlands (Engie, 2024).

- Municipality of Emmen: Emmen holds a strategic position in the ‘Nedersaksenlijn’ given its significant industry, including the gas purification plant (GZI Emmen). The ‘GZI Next’ project aims to explore sustainable activities for this location, potentially including hydrogen production and a hydrogen filling station (GZI Next, 2024).

- Interreg: A European financing instrument with a focus on pioneering and environmentally friendly solutions for regional challenges in Europe (Interreg, 2024).

- Oost NL: The regional development agency (ROM) in Overijssel. The ROM strengthens the regional economy by innovating in sustainability, investing in fast-growing businesses, and attracting and retaining foreign companies in the region (Oost NL, 2024).

- NOM: The regional development agency for Groningen, Drenthe, and Friesland. It strengthens the regional economy by innovating in sustainability, investing in fast-growing businesses, and attracting and retaining foreign companies in the region (NOM, 2024).

- New Energy Coalition (NEC): A network of knowledge institutions and businesses collaborating to accelerate the energy transition for a sustainable future. While its primary focus is on Groningen, Drenthe, and Friesland, the network also engages in (inter)national partnerships with regions and countries (New Energy Coalition, 2024a).

- Holthausen Clean Technology: A company located in Hoogezand, primarily dedicated to converting vehicles into hydrogen vehicles. This entity has extensive knowledge of the use of hydrogen in mobility and is additionally responsible for hydrogen refueling stations (Holthausen Energy Points, 2024).

- Residents of Groningen, Drenthe, and Overijssel.

- Environmental Organizations

In conducting the analysis, it is initially crucial to differentiate between primary and secondary stakeholders. Primary stakeholders, being the key contributors, also align most closely with the project's interests. Their influence Is often important and plays a significant role in the project's success. On the other hand, secondary stakeholders are relatively further removed from the project but share common interests. Importantly, it does not imply that the influence of these stakeholders is less compared to the primary stakeholders. The secondary stakeholders are not actively engaged in the day-to-day execution or decision-making of the project (Currie, Seaton & Wesley, 2009).

Below, the primary stakeholders are listed, considering their interests and influence (power) on the project.

Primary Stakeholders

Province of Groningen, Drenthe, and Overijssel
The development of the 'Nedersaksenlijn' and the determination of the type of train that will be operational are initiatives led by the Provinces of Groningen, Drenthe, and Overijssel (Province of Groningen, Drenthe & Overijssel, 2024). The interests of these stakeholders primarily revolve around regional mobility improvement, sustainability, and positive economic developments in the region. The provinces influence local infrastructure and actively participate in decisions related to mobility.

ProRail
This stakeholder is responsible for the construction of the railway track and implementing necessary adjustments (ProRail, 2024b). The primary interest lies in efficient railway management. When introducing hydrogen, considerations must be made for a heavier vehicle than usual (adjustment of the soil), potentially involving detours to refueling stations. ProRail's task is to ensure and manage safety, therefore, the influence of ProRail is crucial in decisions related to the railway infrastructure.

Arriva
In its role as the service provider, Arriva holds responsibility for operating a train on this regional railway line. Arriva has a direct interest in the successful implementation of a hydrogen train, aligning with its commitment to promoting sustainability and green passenger transport. Furthermore, it can enhance its reputation as a sustainable transportation company. The influence of Arriva is moderate and depends on the policy decisions made by the provinces and ProRail. This influence is exercised through discussions and collaborations.

Ministry of Infrastructure and Water Management
As a department within the Dutch government, the Ministry of Infrastructure and Water Management plays a significant role in national mobility policy and infrastructure. Sustainability is an important consideration in its interests. This department holds influence over the policymaking of national infrastructure projects.

Ministry of Economic Affairs and Climate
The department, specifically orientated toward achieving a climate-neutral society with a strong an open economy concentrated on coordinating economic policies in connection with sustainability. Concerning the potential of a hydrogen train on this railway, this stakeholder holds a policy influence. Additionally, it manages permits that have implications for the implementation of a hydrogen train.

NAM (Nederlandse Aardolie Maatschappij – Dutch Oil Company)
This national institution has historically supplied energy to society and industry, primarily through natural gas. Since the cessation of natural gas, the focus has shifted, and the current emphasis for the NAM is on the implementation of hydrogen as an alternative energy source (NAM, 2024). The interest of the NAM revolves around ensuring safe and efficient storage and transport of hydrogen. In a project like the 'Nedersaksenlijn', where the potential of hydrogen is explored, the influence of the NAM primarily lies in its involvement in hydrogen logistics and infrastructure.

Hynetwork Services
A subsidiary of Gasunie responsible for establishing a hydrogen network in the Netherlands, Hynetwork Services' main interest lies in the development of hydrogen infrastructure and its impact on the regional economy. The focus includes considering the possibility of fostering more hydrogen related businesses in various locations across the Netherlands. In this project, the stakeholder's influence primarily lies in its role of constructing the hydrogen network in the Northern Netherlands, with the identification of favorable locations for protentional hydrogen refueling station and storage places.

Alstom
As an international company in the sustainable transportation sector, Alstom concentrates on the development and sale of hydrogen trains in Europe. It is also engaged in technological advancements related to heavy hydrogen vehicles. The influence of Alstom relies in this context on its ability to serve as a supplier of hydrogen trains on this railway. Consequently, the company can actively participate in the project implementation of a hydrogen train between Groningen and Enschede.

Engie
An energy company engaged in the production and distribution of electricity and natural gas, as well as providing services to the energy sector, Engie is currently part of the green hydrogen chain in North Netherlands (HydroNetherlands). Engie is responsible for supplying green hydrogen and installing refueling facilities to promote sustainability. This stakeholder positively influences the project as a hydrogen supplier. Furthermore, Engie possesses knowledge of implementing hydrogen in trains and hydrogen refueling stations, contributing to the overall hydrogen infrastructure in the Netherlands.

Municipality of Emmen
Emmen has a strategic position due to its geographical location and the presence of a significant industry, including the gas purification plant (GZI Emmen). With the reduction in natural gas usage, the focus has shifted towards sustainable energy. The GZI Next project will investigate sustainable initiatives at this site, including hydrogen production and distribution (Gasunie, 2024a). Exploring this industry/location is crucial for realizing hydrogen in the 'Nedersaksenlijn'. Emmen's interest in the GZI Next project primarily revolves around enhancing the sustainability of the city and the region. The municipality's influence on the 'Nedersaksenlijn' project primarily stems from its role in local governance and regional developments.

Interreg
This European financing entity will contribute to the possibilities of hydrogen in the 'Nedersaksenlijn'. It is crucial to evaluate the funding level that Interreg can offer for this project. The significance and influence of this stakeholder are both considerable.

New Energy Coalition (NEC)
This network compromising knowledge institutions and businesses accelerates the pace of the energy transition. With multiple knowledge institutions and businesses involved, this stakeholder holds a crucial position, bringing expertise to the energy transition. The primary interest of this party is the energy transitions towards a sustainable future, and its knowledge significantly impacts the research into the potential of hydrogen in the 'Nedersaksenlijn' and its surroundings.

Holthausen Clean Technology
This family-owned business located in Hoogezand plays an important role in the hydrogen environment in the Northern Netherlands. The company is involved in converting existing fossil fuel vehicles into hydrogen vehicles and oversees hydrogen refueling stations in the region, known as 'Holthausen Energy Points' (Holthausen Energy Points, 2024). This stakeholder aims to be responsible for sustainable refueling stations in the region's future, offering opportunities for a potential refueling station for hydrogen trains in the 'Nedersaksenlijn'.

Secondary Stakeholders

Oost NL
This regional development agency, with a focus on Overijssel, holds a crucial position in the regional economy. When exploring the potential of hydrogen, it is essential not to underestimate this stakeholder. Their objectives include regional development, investments in sustainability, and facilitation of business establishments in the region. Initiatives promoting hydrogen usage, such as introducing a hydrogen train in the 'Nedersaksenlijn', generate demand for hydrogen-related businesses in the region. The influence of this stakeholder will primarily be at the regional level, with a focus on developing and supporting hydrogen initiatives.

NOM
This regional development agency, concentrating on Groningen and Drenthe, is crucial to the regional economy. When exploring the potential of hydrogen, it is essential not to underestimate this stakeholder. Their objectives include regional development, investments in sustainability, and facilitation of business establishments in the region. Initiatives promoting hydrogen usage, such as introducing a hydrogen train in the 'Nedersaksenlijn', generate demand for hydrogen-related businesses in the region. The influence of this stakeholder will primarily be at the regional level, with a focus on developing and supporting hydrogen initiatives. NOM has a partnership with NEC (New Energy Coalition).

Residents of Groningen, Drenthe, and Overijssel
Because part of the railway line still needs to be constructed, and the potential establishment of a hydrogen network may occur, this project has implications for the environment and the community. Key concerns of local communities primarily revolve around environmental protection and safety. The influence of this stakeholder on the project primarily resides in opinions and the acceptance of hydrogen projects.

Environmental Organizations
For this project, adjustments will be required in the environment, including installing new railway tracks, hydrogen refueling stations, and hydrogen storage facilities. These changes will impact the environment based on how they are implemented. The primary interests of environmental organizations will revolve around sustainability and nature protection. The initial phase may not raise many concerns when promoting hydrogen use, but understanding its potential impact on the physical nature will be a more significant challenge. The influence of this stakeholder on the project will be through influencing policy formulation and regulations related to environmental issues.

Schematic overview of the stakeholders

Table 1: Schematic table of the primary stakeholders (made by author, 2024)

Stakeholder	Interests	Influence	Involvement	Attitude
Province of Groningen, Drenthe & Overijssel	Regional mobility improvement, sustainability, economic development.	On local infrastructure and mobility decisions.	Actively involved in local projects, positively critical.	Positive, if it stimulates regional development and sustainability goals.
ProRail	Efficient railway management, and sustainable mobility.	Important role in the rail infrastructure. Development of new rail facilities or the adjustment of it.	Active in rail projects, proactive in infrastructure development.	Positive, if the project improves the railway infrastructure and ensures safety.
Arriva	Sustainability & Operational Efficiency.	Policy decisions	Direct impact on services.	Positive, if project aligns with sustainability goals.
Ministry of Infrastructure and Water Management	National mobility policy, sustainability, infrastructure.	Policy making, national infrastructure projects.	Active in policy making, coordination in national projects	Positive, if the project aligns with national policy goals and promotes sustainability.
Ministry of Economic Affairs and Climate	Coordination of economic policy, and sustainability.	Policy making, permit coordination.	Active role in economic policy, coordination of permits.	Positive, if the project contributes to climate goals and promotes clean, reliable energy.
NAM	Safe and efficient hydrogen storage and transport.	Involvement in hydrogen logistics and infrastructure.	Active in hydrogen related projects, involved in infrastructure developments.	Positive, if the project aligns with future sustainability goals for gas infrastructure.
Hynetwork Services	Development of hydrogen infrastructure, regional economy.	Crucial role in the construction of the hydrogen network in the Northern Netherlands.	Leading role in hydrogen infrastructure, regionally involved.	Positive, if the project contributes to the development of hydrogen infrastructure.
Alstom	Development and sales of hydrogen trains, technological progress.	Supplier of hydrogen trains, involvement in project implementation.	Actively involved in implementation, technologically innovative.	Positive, if the project promotes the sale of hydrogen trains and contributes to sustainability in the transportation sector.
Engie	Development and sales of hydrogen trains, technological progress.	Supplier of hydrogen trains, involvement in project implementation.	Actively involved in implementation, technologically innovative.	Positive, if the project promotes green hydrogen production and aligns with the company's sustainability goals.
Municipality of Emmen	Sustainable activities at GZI location.	Local governance and influence on local developments.	Actively involved in GZI Next and sustainability projects.	Positive, if the project promotes sustainable activities and aligns with local policy goals.
Interreg	Financing innovative solutions and sustainable projects in Europe.	Funding at the European level.	Funding partner for regional development.	Positive, if the project aligns with the innovation and climate goals of Interreg and contributes to the European hydrogen economy.
New Energy Coalition	Acceleration of the energy transition of a sustainable future.	Expertise in energy transition and sustainability.	Active role in regional an international collaboration.	Positive if it contributes to energy transition and sustainability goals.

Table 2: Schematic table of the secondary stakeholders (made by author, 2024)

Stakeholder	Interests	Influence	Involvement	Attitude
Oost NL & NOM	Strengthening of the regional economy.	Focused on regional economic developments	Actively involved in sustainability innovations in the region.	Positive, if the project strengthens the regional economy and aligns with sustainability goals.
Residents of Groningen, Drenthe, and Overijssel	Safety in the region and environmental protection.	Opinions and acceptance.	Moderate, impact on the local community.	Variable, depending on individual perspectives.
Environmental Organizations	Sustainability and environmental protection.	Influence on policy formulation and regulations.	Role in environmental issues.	Positive, if sustainability is promoted, and the environment is minimally burdened.

Tables 1 and 2 present a structured overview of the interests, influence, involvement, and attitudes of all stakeholders, both primary and secondary. Identifying interests enhances our understanding of the objectives pursued by each stakeholder. Determining influence allows us to recognize which stakeholders can significantly impact decision-making regarding hydrogen-related issues. Structuring the involvement is a crucial aspect of fostering effective communication and collaboration. Lastly, it is important to examine the attitudes of the various stakeholders. To ensure the success of the project and capitalize on hydrogen opportunities in the 'Nedersaksenlijn', it is imperative to evaluate when different stakeholders will embrace a positive attitude towards the project. This involves considering what is needed for stakeholders to adopt a favorable stance on the project.

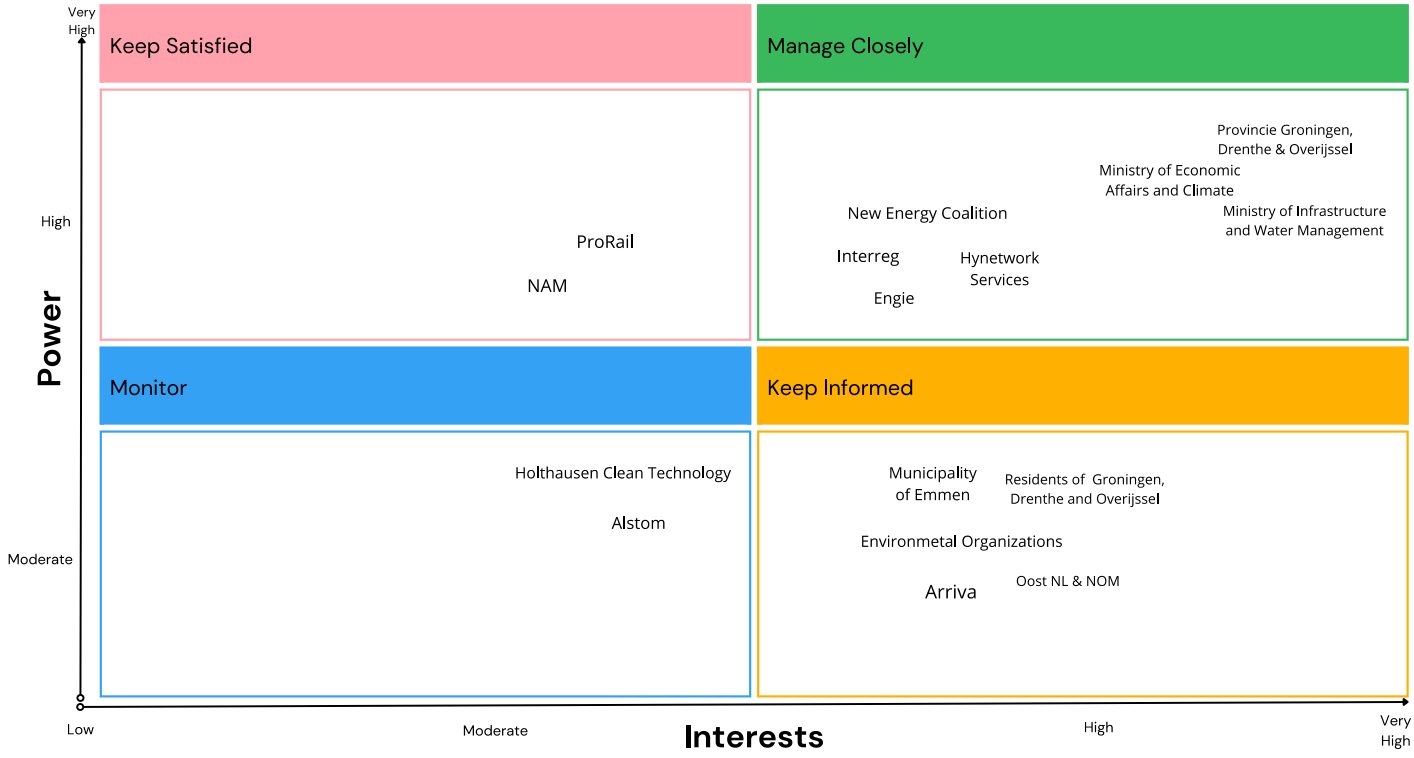
Stakeholder matrix

In addition to identifying primary and secondary stakeholders, a stakeholder matrix has been employed. This stakeholder management tool provides a more structured overview of the various stakeholders and their involvement in the project. The stakeholder matrix has been completed considering the interests and influence of each stakeholder. For each stakeholder, the level of interest and influence (power) on the projects and their outcomes has been assessed and categorized from low to very high. Table 3 presents a schematic overview of the level of interest, influence, and involvement of all stakeholders. With this, the matrix, which is presented in Figure 1, has been made.

Table 3: Schematic overview of Interests, Influence, and Engagement (made by author, 2024)

	Interests (Low, Moderate, High & Very High)	**Influence (Low, Moderate, High & Very High)**	**Engagement (Low, Moderate, High & Very High)**
Province of Groningen, Drenthe, and Overijssel	Very High	High	Very High
ProRail	Moderate	High	High
Arriva	High	Moderate	High
Ministry of Infrastructure and Water Management	Very High	High	Very High
Ministry of Economic Affairs and Climate	Very High	High	High
NAM	Moderate	High	Moderate
Hynetwork Services	High	High	High
Alstom	Moderate	Moderate	Moderate
Engie	High	High	High
Municipality of Emmen	High	Moderate	Moderate
Interreg	High	High	High
Oost NL & NOM	High	Moderate	Moderate
New Energy Coalition	High	High	High
Holthausen Clean Technology	Moderate	Moderate	Moderate
Residents of Groningen, Drenthe, and Overijssel	High	Moderate	Moderate
Environmental Organizations	High	Moderate	Moderate

Figure 1: Stakeholder matrix (made by author, 2024)



This stakeholder matrix provides an overview of all relevant stakeholders along with their position in the matrix. This allows for a distinction within the overall stakeholder group. By identifying key figures, we gain insights that enable us to concentrate efforts on these stakeholders, optimizing the project's chances of success. Additionally, it clarifies which parties need to be primarily informed to maintain a positive attitude among these stakeholders.

The information derived from this matrix will contribute to more effective and targeted future steps, resulting in an increased likelihood of success. Ultimately, through collaborative efforts with key figures, ensuring the satisfaction of the 'keep satisfied' stakeholders, involving the observer, and providing regular updates to the interested stakeholders on development and progress, a strong partnership will be fostered.

Challenges for the future

Having identified all stakeholders, it is crucial to analyze the future challenges associated with implementing hydrogen in the 'Nedersaksenlijn'. This examination aims to determine which stakeholder(s) can contribute to addressing these challenges.

Infrastructure & Technology

- Adapting the railway infrastructure for a hydrogen train involves substantial investment and significant time commitment. Moreover, consideration for safety measures and potential detours to hydrogen refueling stations are essential.
- The technical complexity of establishing hydrogen refueling stations and storage facilities near the railway line demanding careful planning, requiring collaboration among stakeholders.

Safety & Regulation

- The introduction of a new train model, specifically the hydrogen train, requires a comprehensive safety assessment, mainly due to its increased weight. It is essential to closely examine the impact of this increased weight on both the railway and the underlying ground. The integration of hydrogen into the railway sector and the broader region is dependent on obtaining various permits and complying with laws and regulations regarding hydrogen transport and usage.

Financing

- Challenges arise in securing sufficient funding for the implementation of the hydrogen train, the development of hydrogen infrastructure, and the necessary modifications to the overall infrastructure.
- The economic viability of the project presents a challenge, considering the costs associated with hydrogen and operational expenses.

Engagement & Acceptance:

- The support and acceptance of local communities in the changes to the environment and region are crucial for the success of the project.

Environmental Impact & Sustainability

- Implementing changes in the physical environment, like establishing a hydrogen network and new refueling stations, will be challenging for the concerns of environmental organizations.
- Moreover, ensuring the production of green hydrogen is a critical factor in maintaining the project's environmental benefits.

Figure 2: The challenges along with the associated stakeholders (made by author, 2024)

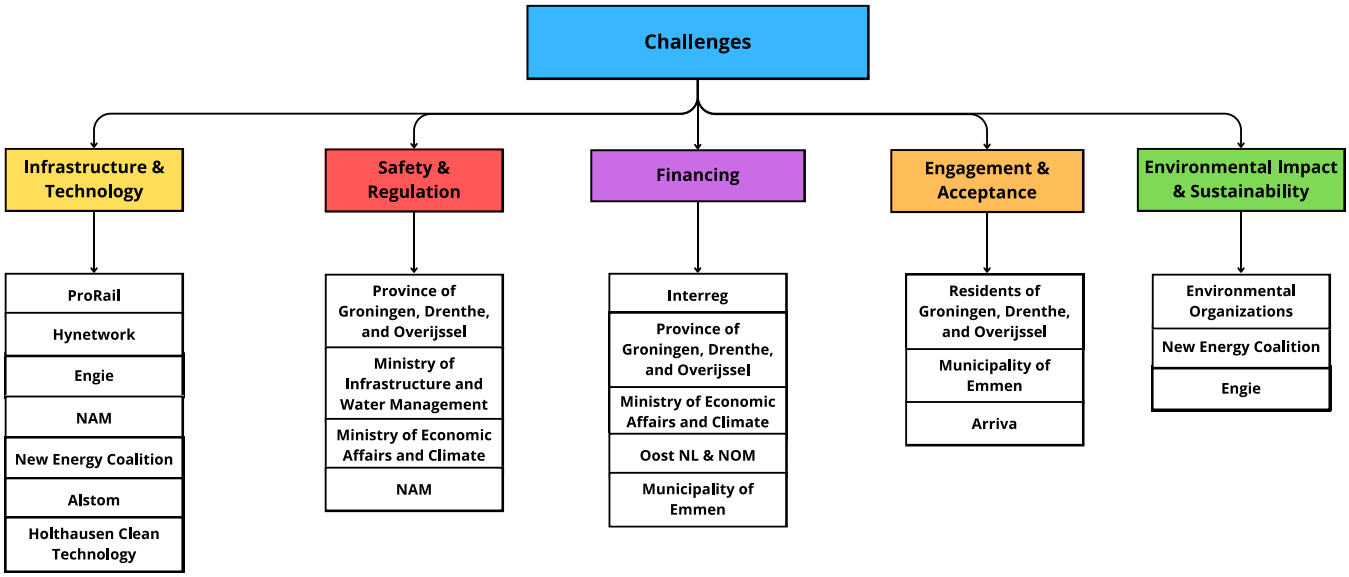


Figure 2 provides an overview of the challenges and the associated stakeholders capable of influencing these specific challenges. Each challenge involves multiple stakeholders, emphasizing the need for effective collaboration. The collaborative effort considers the expertise of each stakeholder, enabling them to complement one another within their respective domains. This collaborative approach is designed to boost the success of the hydrogen implementation in the 'Nedersaksenlijn' and its surroundings.

Conclusion

This stakeholder analysis provides a detailed insight into the various stakeholders involved in the implementation of hydrogen in the 'Nedersaksenlijn'. The analysis has offered an overview of the interests, influences, involvement, and attitudes of both primary and secondary stakeholders. From this overview (Table 1 & 2), it became clear that the interests and influences of the stakeholders vary significantly. The matrix (Figure 1) provides a comprehensive snapshot of each stakeholder's current position within the project. Additionally, challenges in infrastructure, safety, financing, engagement, and environmental impact are emphasized (Figure 2).

The successful implementation of hydrogen requires close collaboration among a diverse range of stakeholders, taking into consideration their individual interests and influence. The strategic mapping of potential collaborations (Figure 2) is crucial to ensuring the project's sustainable success.