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Green Hydrogen Future: Comparative Analysis of Belgian and Dutch Government Strategies for Industrial Adoption

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Masters' Thesis - Energy
Master Environmental & Energy Management
Academic Year 2023/2024

Abstract

Green hydrogen made of renewable energy, has a pivotal role in decarbonising the industry. Besides, green hydrogen is already used as a feedstock in the industry for the manufacturing of chemicals, refineries, steel production, etc. The interest in (green) hydrogen is growing and several countries launched a hydrogen strategy. Despite the increasing attention, green hydrogen is still struggling to take off significantly and is yet considered a niche or protective space. Effective protection consists of three elements – shielding, nurturing and empowerment (SNE) – which are defined in the SNE framework. This framework enables the identification of shortcomings and characteristics of effective protection which can help to pave a socio-technical transition pathway within the broader Multi-Level Perspective (MLP) for green hydrogen into both the manufacturing regime and the energy regime.

The hydrogen strategies of Belgium and the Netherlands are chosen based on their frontrunner role regarding green hydrogen and are considered an extreme case. A thematic analysis of the governmental strategies is complemented by industrial stakeholders' perceptions extracted from semi-structured interviews with a focus on the SNE characteristics and the socio-technical transition pathways. The Belgian and Dutch hydrogen strategy mainly envisioned a transformation pathway compromising an undeveloped green hydrogen niche while pressure from the Green Deal occurred leading to an adjustment into the direction of the green hydrogen development path and reorienting the innovative activities of incumbent actors. This pathway is desired by industrial stakeholders as well. Despite the pressure of the Green Deal, ineffective protection can be identified for both countries. Firstly, inadequate shielding is noticed by low and misallocated funding. Secondly, the key aspects of nurturing are present, however further improvement is noted. Lastly, the Renewable Energy Directive III tends to have a disempowering effect on the green hydrogen niche. These remarks demand an integral approach to obtain effective protection of the green hydrogen niche and facilitate regime integration. The green hydrogen niche impacts the manufacturing and energy regime differently: in the manufacturing regime, green hydrogen is desired to be the main share of feedstock. In this regime, fertiliser and refinery companies seem to have a huge influence on the emergence of the green hydrogen economy. Within the energy regime, green hydrogen only tends to be a part of the energy mix according to the stakeholders of both countries and should be complemented with other technological solutions.

The main differences between Belgium and the Netherlands lie in the higher local green hydrogen production potential, more financial resources, more agreements (but less in-depth) and a more developed status of hydrogen acceptance in the case of the Netherlands. Belgium prioritises electricity while the Netherlands seeks for green hydrogen to solve grid congestion issues. These two front-running countries regarding hydrogen demonstrate the need for effective protection to increase the chances of a successful implementation of hydrogen into the industrial regimes. This is a pivotal step toward a carbon-neutral society and to ensure a sustainable future.

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Abbreviations

ATR	Auto-Thermal Reforming
BE	Belgium
Benelux	Belgium, the Netherlands and Luxembourg
CAPEX	Capital Expenditures
CBAM	Carbon Border Adjustment Mechanism
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
CREG	Commission for Electricity and Gas Regulation
DEI+	Energy Innovation Demonstration Scheme
EECM	Electrochemical Conversion & Materials Programme
ETS	Emission Trading System
EU	European Union
FID	Final Investment Decision
FPS Economy	Federal Public Service Economy
GO	Guarantee of Origin
GW	GigaWatt
IPCEI	Important Project of Common European Interest
LCOH	Levelised Cost of Hydrogen
MLP	Multi-Level Perspective
MMIP	Multi-year Mission-driven Innovation Programme
MOOI	Mission-oriented Research, Development and Innovation
MoU	Memoranda of Understanding
MW	MegaWatt
NGO	Non-Governmental Organisation
NL	The Netherlands
NSEC	North Sea Energy Cooperation
OPEX	Operational Expenditures
R&D	Research & Development
RED (II, III)	Renewable Energy Directive (II, III)
RFNBO	Renewable Fuel of Non-Biological Origin
RVO	Rijksdienst voor Ondernemend Nederland
SDE++	Sustainable Energy Production and Climate Transition Incentive
SME	Small, Medium Enterprises
SMR	Steam Methane Reforming
SNE	Shielding, Nurturing and Empowerment
SNM	Strategic Niche Management
TWh	TerraWatthour
UK	United Kingdom

Acknowledgement

The past quartile was quite heavy with ups and downs. First I want to thank my supervisor dr. E. J. Aukes for the excellent guidance throughout the master's thesis process. We had good discussions and the frequent meetings made me comfortable that what I was doing was worth it. Thank you for all your time and constructive feedback leading to a huge improvement of the script. This kind of engagement from a supervisor is definitely valuable and I would recommend to continue this way to guide future students. Next, I want to thank my 2nd supervisor dr. A. Votsis for the feedback on my draft version in order to make the thesis more understandable.

Special attention goes toward the interviewees that I was able to contact. I appreciate their valuable time to talk with me and their sincere and valuable answers regarding my questions. Especially, the notion after the interview to receive the final report approved their interest in my research which gave me extra motivation.

I also want to thank my parents and my girlfriend, Ine, for their time to listen to my progress and frustrations and to support and encourage me to get through the process. Without them, the writing of the whole thesis would be less motivating. Also, my parents gave me the chance to study for an additional master and I could not afford a better MEEM class to make my entire learning period in Leeuwarden a pleasure.

Chapter 1 Introduction

Climate change is a global issue with severe consequences for humans and ecosystems. To reduce global warming, the EU imposed the Green Deal where all EU Member States have to be climate-neutral by 2050 (European Commission, 2021). The CO_2 emissions, mainly originating from fossil fuels, have to be diminished drastically and renewable energy is considered a replacement for fossil fuels (Ritchie et al., 2023; Kovač et al., 2021). The intermittency of renewable energy like wind and solar energy requires the exploration of alternative energy sources or carriers such as hydrogen gas, geothermal, biomass, etc. Hydrogen is considered a promising alternative energy carrier for fossil fuels and a solution for processes unsuitable for electrification (Ministry of Economic Affairs & Climate, 2024). Also, hydrogen has the highest energy density per mass of all fuels and the combustion of hydrogen produces unharmful water with negligible emissions (Royal Belgian Academy Council of Applied Science, 2006). Besides, hydrogen is a feedstock in the industry for ammonia, methanol, refineries, etc. making the hydrogen path increasingly interesting to explore (Griffiths et al., 2021).

The EU and several Member States are exploring the opportunities of hydrogen and created a hydrogen strategy, including Belgium and the Netherlands. Recently, the European Court of Auditors noted that the targets of import and production of renewable hydrogen for 2030 are unrealistic (ECA, 2024). Hydrogen has different production methods and a colour is assigned to each method (Figure 1). Green hydrogen or renewable hydrogen is made free of CO_2 emissions with renewable energy compared to conventional fossil-based Steam Methane Reforming (SMR), so-called grey hydrogen (Romm, 2013; EERE, n.d.). Green hydrogen plays a vital role in the energy transition and in achieving a carbon-neutral society.

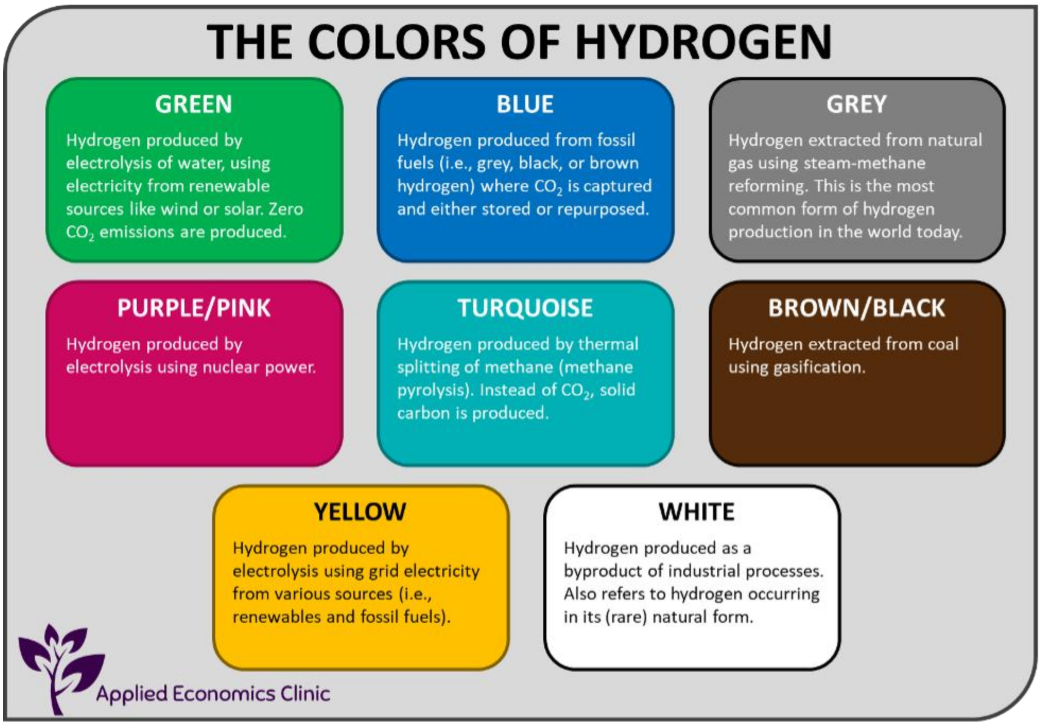

Figure 1. Hydrogen colours and corresponding production methods (adapted from Majumder, 2021).

Green hydrogen is not yet competitive with fossil-based hydrogen due to several challenges (Brandt et al., 2024). Firstly, green hydrogen is not cost-competitive with fossil-based hydrogen and the intermittency of renewable energy does not promote the use of green hydrogen as a stable baseload is desirable within the manufacturing industry (Furfari & Clerici, 2021). Secondly, the hydrogen market with infrastructure and networks is struggling to develop, making the green hydrogen niche less attractive despite the opportunities of the niche and the implementation of the Renewable Energy Directive III[1] (RED III). Niches are protective spaces and need effective protection to integrate into the regime. Green hydrogen is still considered a niche, possibly due to ineffective protection of the protective space. The effective protection of niches has already been investigated for low-carbon transitions e.g., solar PV, CCS and offshore wind but not yet for green hydrogen (Raven et al., 2016). In this thesis, the effective protection of the green hydrogen niche will be evaluated in governmental hydrogen strategies by using the SNE framework. This framework enables the identification of shortcomings and characteristics of effective protection which aid to pave a socio-technical transition pathway within MLP for green hydrogen. Also, the impact of the green hydrogen niche on the industrial manufacturing and energy regimes will be identified to demonstrate potential differences since the competition for green hydrogen is different in both regimes. Within the manufacturing regime, competition exists between hydrogen production methods and within the energy regime, green hydrogen has to compete with other energy sources.

1.1 Research Questions

This study will focus on the following research question:

"How do industrial stakeholders align their visions with governmental strategies concerning the uptake of green hydrogen into industrial regimes?"

This can be divided into two subquestions namely,

> *"What pathways for regime integration of the green hydrogen niche do the Belgian and Dutch governments envision?"*
>
> *"How differently does regime integration of the green hydrogen niche impact the manufacturing and energy regimes in Belgium and the Netherlands?"*

The socio-technical regime level is very complex since many regimes exist, even in the industry. The green hydrogen niche can influence different regimes but the most profound where green hydrogen can play a role in the industry is within the manufacturing and energy regime. Answering both subquestions required a thematic analysis of governmental strategies and semi-structured interviews using the SNE framework and the transition pathways within MLP. However, the themes and focus of both subquestions differ.

1.2 Thesis Outline

The thesis will consist of a Theory chapter (Chapter 2) containing the theoretical approach. Next, the research methodology is explained in the Research Design (Chapter 3). Afterwards, the Results are presented (Chapter 4) followed by a Discussion chapter containing the results obtained (Chapter 5), after which a conclusion follows (Chapter 6). At the end, the References and Appendix can be found and accessed.

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[1] RED III sets obligations that a share of green hydrogen consumption for final energy and non-energy purposes should be 42,5% by 2030 and 60% by 2035 (Directive 2023/2413). Also, RED III sets additional criteria when green hydrogen is classified as renewable fuels of non-biological origin (RFNBO) hydrogen (Commission Delegate Regulation (EU) 2023/1184).

Chapter 2 Theoretical Approach

This chapter consists of the theoretical approach. First, the Multi-Level Perspective will be introduced as this theoretical framework is the foundation for studying transitions. The interaction between the levels leads toward the transition pathways section as defined by Geels & Schot (2007). The chapter ends with a zoom on the lowest MLP level, the niche, where the concepts for effective protection of a niche will be explained by the conceptual SNE framework.

2.1 Multi-Level Perspective

The Multi-Level Perspective (MLP) has recognised the deep interconnection between society and technology as they are intertwined. Practices adopted by firms and other actors collectively define a technological regime and its trajectories. These technological paths are further broadened by incorporating 'rules' that account for the sociological aspect, acknowledging the co-evolution of society and technology within the MLP (Geels, 2002; Rip & Kemp, 1998). By comprising three heuristic and analytical components, the MLP framework facilitates comprehension of complex dynamics of changes in socio-technical systems (Geels, 2002). These levels consist of a landscape (macro-level), a patchwork of regimes (meso-level) and novel niches (micro-level), interconnected in a nested hierarchical structure (Figure 2) (Grin et al., 2010). Niches are no predefined models but serve as valuable sources for new capabilities and transformations (Grin et al., 2010). However, the development of niche innovations is frequently hindered by various challenges (Geels, 2019). These innovative niche technologies often incur higher costs compared to conventional technologies, primarily because their novelty prevents economies of scale. Furthermore, markets are not yet ready for niche innovation. Users remain locked in due to the perception that new technologies are unreliable or unfamiliar (Geels, 2019). Therefore, Strategic Niche Management (SNM), a subset of the MLP, attempts to tackle the barriers preventing the niche for regime integration (Jenkins & Hopkins, 2018). SNM is an effort to create space to protect novel technologies from the regime (Loorbach & Van Raak, 2006). Regimes are established upon a set of rules and actors following them. Socio-technical regimes serve societal functions and are stable (Grin et al, 2010). Generally, regimes display resilience against change often due to lock-in effects (Raven et al., 2011). Regimes are commonly perceived as coherent and homogeneous, this representation often diverges from reality (Fuenfschilling & Truffer, 2014). Finally, landscapes influence actions by presenting opportunities and limitations through their gradients (Rip, 2012). Landscape elements question the current regimes and open windows of opportunity for niches (Smith et al., 2010).

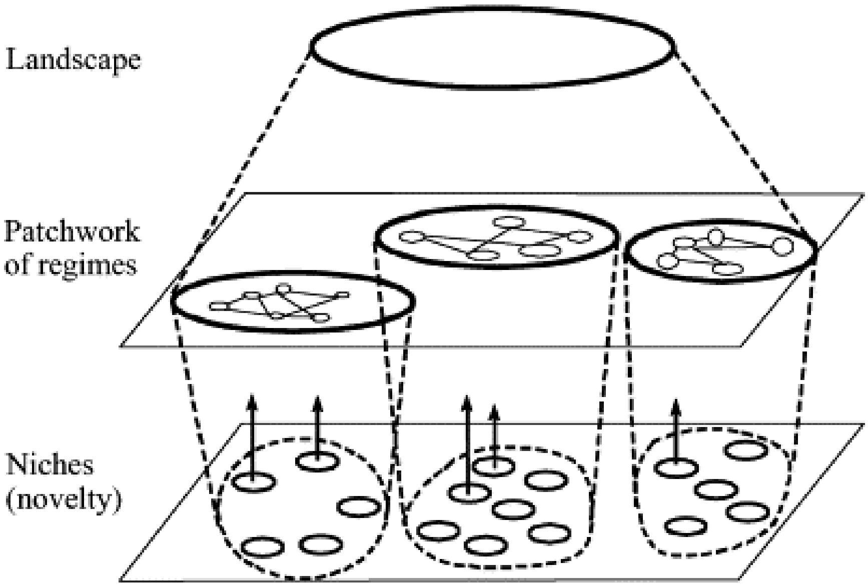

Figure 2. Nested hierarchy of MLP (adapted from Geels, 2002)

2.2 Transition Pathways

Geels & Schot (2007) describe transitions as the interplay among the levels of the MLP including niches building up internal momentum and landscape pressures toward socio-technical regimes. The MLP approach enables the identification of characteristic patterns shaping a pathway (Elzen & Hofman, 2007). Geels & Schot (2007) developed types of transition pathways based on time and kinds of multi-level interaction which are a further conceptualisation of the MLP (Verbong & Geels, 2010): the first pathway is the transformation path where a disruptive change (moderate landscape pressure) occurs when the niche is not developed sufficiently, leading to an adjustment of the direction of development paths and innovation activities of the incumbent actors. The new regime emerges from the old regimes due to gradual adjustments and reorientation; the second pathway is the de- and re-alignment path where cumulative problems within the regimes can lose the confidence of regime actors leading to a de-alignment due to a large landscape change. A real substitute does not exist and the niche or the co-existence of multiple niches can evolve in the created space and re-align a new regime; the third pathway is the technological substitution path where a niche is well developed and a lot of pressure is exerted from the landscape. The existing regime will be completely substituted by the niche; the final pathway is the reconfiguration pathway where niches are developing symbiotic innovations to solve local issues. Over time, they lead to further modifications of the regimes' fundamental structure.

Recent literature suggests the analysis should be broadened to a whole system reconfiguration through a combination of various niche innovations and regime developments, and to move beyond the 'everything is interconnected' idea and focus on the whole systems' architecture (McMeekin et al., 2019; Geels, 2019). Still, the approach of these transition pathways or 'innovation journeys' is commonly used in socio-technical transition research (Geels & Turnheim, 2022). However, several limitations are mentioned by Geels & Turnheim (2022): these innovation journeys are seen as bottom-up biases where the innovation is a driving force (Geels, 2018). Also, the approach of a singular niche overthrowing the regime or struggling against a single existing system is too simplistic. The exclusive focus on the niche can also lead to underestimating the GHG emission reduction potential. Incumbent actors are often seen as inert entities with the consequence that endogenous change is frequently overlooked. Still, it makes sense to analyse innovations according to the transition pathways since incremental improvements are insufficient to achieve significant GHG emission reductions required to avoid climate change (Geels & Turnheim, 2022).

2.3 Shielding-Nurturing-Empowering Framework

Niches are protective spaces with specific protection needs due to their vulnerability to structural pressures of regimes (Kemp et al., 1998; Fuenfschilling & Truffer, 2014). Niche protection received little attention in the literature (Smith & Raven, 2012; Smith et al., 2014). According to Smith & Raven (2012), three key attributes - shielding, nurturing and empowerment - are essential for an effective protection of the niche. This conceptual framework allows analysis of the protective spaces or niches (Verhees et al., 2013). Shielding involves safeguarding the innovation from potential rejection due to a misfit in industrial processes or decisions (Smith & Raven 2012). Shielding creates space for experimentation and repels the niche from mainstream selection environments (Verhees et al., 2013). Shielding is offered by financial support or rule exemptions enabling early research efforts and creating space and the opportunity to nurture within this space (Verhees et al., 2015; Smith & Raven, 2012; Verhees et al., 2013). Nurturing is the most elaborated aspect within the literature (Raven et al., 2016). Schot & Geels (2008) suggested three significant processes of nurturing: encouraging learning processes, robust expectations and establishing social networks. Empowerment is about the increased diffusion of the niche resulting from successful nurturing, and increased competitiveness (Verhees et al., 2013; Schot & Geels, 2008). Empowerment is the least developed within the literature and consists of two types: fit-and-conform and stretch-and-transform (Smith & Raven, 2012). The fit-and-conform empowerment consists of removing the shielding and successfully integrating the niche into the regime under conventional criteria (Verhees et al., 2013). The stretch-and-transform empowerment tends to change the existing rules of the regime in favour of the niche (Raven et al., 2016).

The SNE framework is relevant to analyse the green hydrogen niche protection since the protective space of a niche is under-conceptualised (Boon et al., 2014). Smith & Raven (2012) argued that empirical cases should confirm the SNE framework. This has been done with several successful sustainable innovation case studies (e.g., solar photovoltaic electricity and offshore wind) but not yet with green hydrogen (Smith et al., 2014; Verhees et al., 2013; Verhees et al., 2015). The type of studies gave knowledge of the role and effectiveness of governmental policies since policies enable or constrain SNE and are indispensable for effecting change in socio-technical systems (Verhees et al., 2015; Kivimaa & Kern, 2016). Also, studying successful examples provides proven frameworks and adaptable strategies to new contexts leading to avoiding common pitfalls and reducing the learning curve. Lessons can be learned on how to scale innovations from pilot to mainstream adoption and these types of studies provide a holistic view of the socio-technical landscape, illustrating how policy, markets, technology and society interact to support niche integration.

The green hydrogen niche will be explored and the SNE framework will evaluate the effectiveness of niche protection. Possible transition pathways regarding the green hydrogen niche will be identified to obtain a broad understanding of the socio-technical transition of green hydrogen towards decarbonisation.

Chapter 3 Research Design

To answer the research questions and the corresponding subquestions, a qualitative assessment approach was conducted (Figure 3). It points out which steps are undertaken during the research such as case selection, data gathering, data analysis and findings. Further elaboration is provided in the sections below.

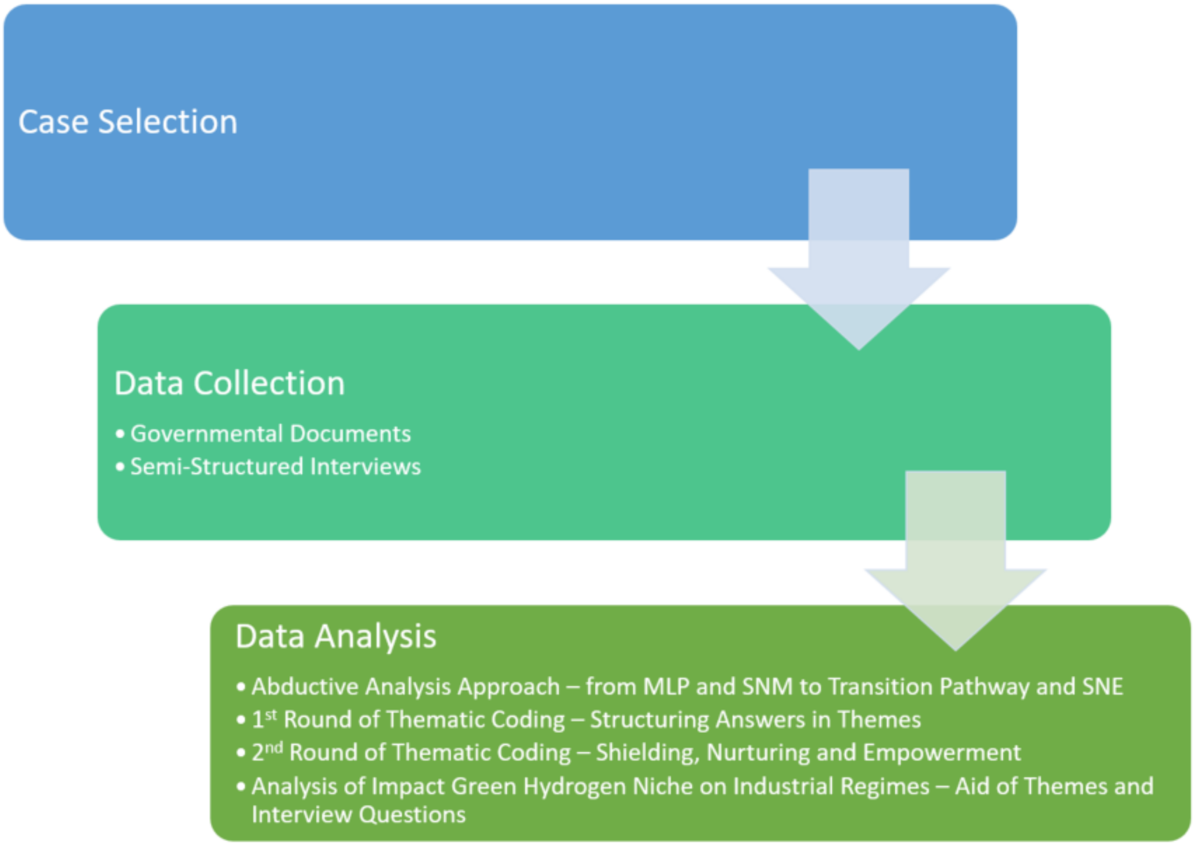

Figure 3. Methodology of the research

3.1 Case Selection

The case selection can be divided into two parts, the first part is the reasoning behind the choice for Belgium and the Netherlands. Both are neighbouring EU member states and both have developed a hydrogen strategy (FPS Economy, 2022; Ministry of Economic Affairs & Climate, 2020). According to the FPS Economy (2022), Belgium is aiming to expand their leadership in hydrogen technologies and establish a robust hydrogen market (FPS Economy, 2022). On the other side, the Netherlands wants to possess and secure a prominent role in the hydrogen transition in Europe (Ministry of Economic Affairs & Climate, 2020). Both countries are located next to the North Sea and have similar weather conditions making the renewable energy production per area for green hydrogen production similar. A difference in effectiveness and efficiency is likely due to policies and economic-related factors which is interesting to investigate. Both countries differ in their energy mix as the Netherlands and Belgium have a more prominent share in respectively natural gas and nuclear power within their total energy supply (IEA, 2023). This makes it interesting to compare as they apply a hydrogen strategy and have to add it to a different energy mix delivering insightful information regarding perceptions and influences on energy regimes. Both countries can be seen as front runners to integrate the green hydrogen niche, being an example to other countries. This case selection can be considered an extreme case as if both countries are unable to integrate green hydrogen in their industrial regimes, it will be difficult for other countries to achieve a successful implementation.

The second part provides a reason to choose the regimes that will be impacted by the green hydrogen niche. In the industry sector, many regimes can be impacted by the green hydrogen niche, making the analysis extremely complex. Therefore, two regimes are chosen. The first regime is the manufacturing regime where hydrogen is used as feedstock. The second regime is the energy regime where hydrogen can be valuable to decarbonise industrial processes. It is interesting to investigate the impact of these regimes since the role of green hydrogen is different. In the manufacturing regime, green hydrogen has to compete with other types of hydrogen (e.g., fossil-based hydrogen) and in the energy regime green hydrogen has to compete with other energy sources.

3.2 Data Collection

3.2.1 Governmental Documents

To respond to the first subquestion, the governmental hydrogen strategies of Belgium and the Netherlands were studied. Both governmental documents are publicly available on the governmental sites of Belgium[2] and the Netherlands[3].

3.2.2 Semi-Structured Interviews

A snowball sampling technique was used to make a preliminary industrial stakeholders analysis based on knowledge from the researcher and a review of the literature (Griffiths et al., 2021; Topsector Horticulture & Starting Materials, 2022). Semi-structured interviews were conducted to gather insights and perceptions from the industry on hydrogen strategies. The semi-structured interviews provided an assessment of how the green hydrogen niche integration could disrupt or transform the dynamics and structures of existing regimes. The avoidance of structured interviews was undertaken since this could lead to a hindrance in collecting in-depth responses and thus semi-structured interviews were beneficial for obtaining an insightful analysis (Bryman, 2016). Initially, interview questions were created to have consistent information across all conducted interviews. The questions were aligned with the research questions and the theoretical frameworks (Appendix I). All interviews (30-60 minutes) were conducted in Dutch and recorded in Microsoft Teams. A list of interviewees is provided in Table 1.

Table 1. List of interviewees

ID	Interviewee	Country	Role of stakeholder
1	Governmental Advisor Energy Department	BE	Policy-advisor
2	Director Project Development Company	BE	Hydrogen Producer
3	Manager Steel Company	BE	Hydrogen Consumer
4	Director Chemical Company	BE	Hydrogen Producer/Consumer
5	Director Energy Company - Refinery	BE	Hydrogen Producer/Consumer
6	Director Fertiliser Company	BE	Hydrogen Consumer
7	Manager NGO	BE/NL	Hydrogen Collaboration
8	Governmental Advisor Dutch Government	NL	Policy-advisor
9	Business Developer Renewable Energy Company	NL	Hydrogen Producer
10	Business Developer Steel Company	NL	Hydrogen Consumer
11	Business Developer Fertiliser Company	NL	Hydrogen Producer/Consumer
12	Business Developer Energy Company - Refinery	NL	Hydrogen Consumer
13	Director Greenhouse Horticulture Organisation	NL	Hydrogen Consumer

[2] https://economie.fgov.be/sites/default/files/Files/Energy/waterstof-visie-en-strategie.pdf
[3] https://www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen

3.3 Data Analysis

An abductive analysis approach was conducted concerning the use of the theory by using first the broad theories of MLP and SNM toward a more narrow theory during the research leading to the transition pathways and the SNE framework (Timmermans & Tavory, 2012).

To analyse the qualitative data, thematic coding was conducted. Thematic colour coding allows for examining the governmental pathways and the SNE aspects within the governmental strategy documents and semi-structured interviews. An inductive preliminary codebook was developed based on a literature review and the Belgian and Dutch hydrogen strategies by selecting key themes that comprehensively captured the strategies and aligned with indicators of the SNE framework. The transcripts of the semi-structured interviews further validated these themes. However, no colour coding was used within the semi-structured interviews. The themes and their corresponding explanation and colours are displayed in Table 2.

Table 2. Codebook for the governmental strategy and semi-structured interviews and their explanation. The connection with the SNE framework is displayed in italics.

Themes	**Explanation**	**Colour**
Policy Objectives	Stated goals and targets (Rotmans et al., 2001*):* *Policy objectives aim for shared expectations – nurturing*	(red)
Financial Instruments and Funding	Budget allocations and funding mechanisms (subsidies, taxes, exemptions) (Vedung, 1998): *Financial instruments and funding are crucial to protect the green hydrogen niche – shielding*	(green)
Regulatory Frameworks and Non-financial Incentives	Regulatory policies, standards and incentives to promote hydrogen adoption (Vedung, 1998): *Regulatory frameworks and (non)-financial incentives can help facilitate effective protection – all SNE*	(olive)
Hydrogen Production and (Innovative) Technology	Strategies for production and (advancing) hydrogen technologies (Sovacool & Geels, 2016): *Hydrogen production and (innovative) technology are needed to mature and improve the niche – nurturing*	(blue)
Hydrogen Deployment	Deploying hydrogen in various sectors (Sovacool & Geels, 2016): *Hydrogen deployment points out the opportunities for hydrogen consumption and increasing hydrogen acceptance - nurturing*	(grey)
Stakeholder Engagement	Strategies for engaging stakeholders in the development and implementation of hydrogen initiatives (Smith et al., 2005): *The formation of deep networks and shared expectations – nurturing and empowering*	(pink)
International Collaborations	Agreements, partnerships and collaborations with other countries or international organisations (IRENA, 2022): *Formation of deep networks - nurturing*	(cyan)

Afterwards, a second round of thematic coding was used within the previous themes where the three aspects of the SNE framework – shielding, nurturing and empowerment – were the new codes based on indicators from the literature (Verhees et al., 2015; Raven et al., 2016; Smith & Raven, 2012).

To investigate the impact of the green hydrogen niche on the manufacturing and energy regime, all related aspects regarding these predefined regimes were extracted from the themes within the strategy documents and from specific questions from the semi-structured interviews (Appendix I, Questions 2 and 8). No specific codebook was applied.

3.4 Research Ethics

During my previous thesis, I researched ammonia as a hydrogen carrier from a technical perspective. Therefore, hydrogen is a strong personal point of interest. This research will be influenced by the already-known technological knowledge about (green) hydrogen as my previous knowledge can impact how the story about green hydrogen will be told during this research. This reflection about storytelling has also been investigated by Staddon (2017) where it is encouraged to go beyond dominant discourses, academia, etc. within professional and personal energy stories. Throughout the research, the names of the interviewees will be anonymised to guarantee privacy. The participants were informed beforehand about the safety of data storage, the interview protocol and the willingness of the participants.

Chapter 4 Results

Within this chapter, all the information on the governmental strategies and interviewees' perceptions of each country will be classified within the themes (Cfr. 3.3). Afterwards, a comparison of strategies according to the policy advisors of each country (ID1 and ID8) and the NGO interviewee (ID7) will be displayed. The result section will end with the results extracted from the governmental strategies and the interviewees regarding the impact of the green hydrogen niche on predefined regimes. Later in the Discussion chapter, the information within the themes will be categorised and discussed within the SNE framework and the transition pathways followed by a discussion of the impact of the green hydrogen niches on the predefined regimes.

4.1 Governmental Strategies

4.1.1 Belgium

Policy Objectives

The Belgian government announced only green hydrogen will have a share in the energy mix before 2050, but preferably as soon as possible. Fossil fuels will not be eliminated soon (ID2, ID6). Green hydrogen should be the primary source by 2050 and grey hydrogen will be excluded, but by 2040 blue hydrogen, fossil-based hydrogen with capture of CO_2, will still have a role (ID2). The government claimed to be one of the first countries to develop off-shore wind production and announced an increase in offshore wind capacity to 5,4-5,8 GW by 2030 and research if there is a possibility to produce up to 8 GW. Also, Belgium wants to achieve a minimal electrolysis capacity of 150 MW by 2026. However, the Belgian government claimed Belgium and the Netherlands (together with Germany and the North of France) have insufficient renewable energy sources to fulfil their demand and hydrogen import is a must. Belgium recognised the limited capacity for local renewable energy generation and set a goal to import 20 TWh in 2030 and 200-350 TWh in 2050 to fulfil the Belgian hydrogen demand and to carry hydrogen toward neighbouring countries. An agreement, the Esbjerg Declaration, has been made between Belgium, Denmark, Germany and the Netherlands (Esbjerg Declaration) to increase the production of offshore wind capacity in the North Sea to 65 GW and to have a capacity of 20 GW of green hydrogen at 2030. By 2050 these countries want to have 150 GW of offshore wind capacity. Regarding infrastructure, Belgium wants to use 100-160 km of pipelines by 2026 to build a hydrogen network and to transport hydrogen to neighbouring countries by 2028. The strategy mentioned in a lesser extent at which speed or timeframe the targets have to be reached (ID5). The numbers of the targets and the time to achieve them are being kept vague on purpose as the future is uncertain (ID1).

Financial Instruments and Funding

The Belgian government offers financial instruments to fund and invest in green hydrogen projects. The first fund is the so-called 'Energy Transition Fund' which allocates money each year to fund R&D of production, transportation and storage of hydrogen or hydrogen derivatives. The second financial instrument is the 'Clean Hydrogen for Clean Industry' where the government stimulates investments enabling a faster scale-up of commercial applications. A third financial instrument is the 'Call for Import of Hydrogen' funding the development and demonstration of technologies for hydrogen import and hydrogen injection into a hydrogen transportation network. Subsidies are mainly offered from Europe (e.g., Hydrogen Bank, H2Global and IPCEI) (ID2). The total budget of the Hydrogen Bank in the first round was insufficient to provide one large hydrogen-consuming company with 100% green hydrogen (ID7). Subsidies mainly offer CAPEX support of hydrogen production (e.g., IPCEI), but there is a lack of OPEX support and larger budgets are needed (ID7). The financial support of the federal government (e.g., Klimaatsprong) is neglectable (ID2, ID4, ID7). Big energy firms have the power to regulate the pace and development of the hydrogen economy as they receive almost all subsidies though they are mainly responsible for climate change (ID7). No hydrogen economy will emerge if there is no incentive for them to switch from fossil fuels (ID7). Many project developers received money for green hydrogen projects but almost none of the projects were realised or there were no sales due to a lack of demand (ID4, ID5). Few FIDs are made due to the uncertainty in the long term (ID4). Also, some announced projects did not receive a subsidy and no financial support was given downstream the green hydrogen value chain (ID3, ID6). Besides subsidies, price increase mechanisms for fossil-based hydrogen and the future high cost of CO_2 will block the building of new SMR installations (ID2 – ID5). Non-climate-neutral products should be made more expensive (ID2, ID4). In the context of RED III, a failure to reach the green hydrogen share should be penalised to make RED III credible (ID5). Most industries are concerned about RED III by stating green hydrogen production is impossible as no one can/will pay for it (ID3, ID4). The subsidy schemes applicable to RFNBO hydrogen need adjustments to avoid a suffering industry (ID5). The government support the roll-out of VKHyLab, a test infrastructure, by buying areas. Belgium excludes electrolysis activities from excise duties on electricity. In this way, businesses and research centres can gain experience in electrolysis technology. The building of 100-160 km of pipelines has funding from a Belgian funding scheme. The federal government funds a connection to Germany.

Regulatory Frameworks and Non-Financial Incentives

The Belgian government assign support, guarantees or quotas to the most suitable vector in the right sector considering the ‘Energy Efficiency First’ principle. Today, Belgium transport natural gas from Norway and the UK to neighbouring countries. Later on, the federal government wants to support their European partners by providing access to future energy carriers. This partnership will improve the import volumes, the negotiation between European consumers/producers and competition between industrial players. A pipeline offers a ‘network effect’ and trade between connected participants. No distinction is made between businesses to connect to the hydrogen backbone (ID1). The government wants to occupy unused natural gas networks to transport hydrogen. Stimulation of the hydrogen demand is important to emerge a market (ID4). The government can create an incentive or obligate the end consumer to buy a product with a lower carbon footprint, this is part of Agenda 2025 (ID2, ID4). However, there is still demand for fossil fuels due to many advantages such as storage and energy density which renewable energy cannot offer (ID5). Finally, safety is important and special regulations exist for the transport of gaseous products by pipeline. Social acceptance of hydrogen is a must but people are not worried about technology or the dangers of hydrogen (ID2, ID4, ID5). On the other hand, several interviewees noted people indirectly involved in the hydrogen economy are still questioning the safety of hydrogen (ID2, ID5, ID6). The creation of a European Market benefits producers and consumers and supports the roll-out of technologies for the energy transition. Transparency has to be promoted to build up trust, therefore the certification of green hydrogen norms is supported by the federal government. The gas quality standards will be supervised by the Commission for Electricity and Gas Regulation (CREG). Now, you can not prove if hydrogen is green, therefore regulations are needed (ID7). Common market regulations and certification norms will facilitate the market and mutual development to create the first value chain for hydrogen import in the EU. Several interviewees stated to be careful in Europe as the European Green Deal is making hydrogen very expensive meanwhile in America there are green products or products with a lower CO_2 footprint and production price (ID3, ID4, ID7). The European Green Deal should be accompanied by an 'Industrial Deal' where Europe can develop the hydrogen economy instead of becoming a continent with expensive and underdeveloped hydrogen production (ID4). Instead of colours, the focus should be on CO_2 footprint (ID4, ID7). In industries' vision, blue hydrogen will play a role in developing the hydrogen market and transition to green hydrogen (ID2, ID4, ID7). However, the RED III quota does not facilitate blue hydrogens and the focus is too much on green hydrogen (ID2, ID3, ID4, ID7). The industry targets within RED III are the bottleneck because of the additional criteria to classify as RFNBO hydrogen and the targets need to be weakened to avoid a suffering industry (ID5). RED III also has a transportation part and should be translated homogeneous in local regulations to make a fair hydrogen distribution (ID5). Besides RED III, the ETS and CBAM are policies pushing toward low-carbon operations (ID6).

Hydrogen Production and (Innovative) Technology

In Belgium, the presence of minimal electrolysis capacity offers technological advancements and expertise for Belgian businesses to create credibility. However, local green hydrogen production has been wrongly swept from the strategy as Belgium should possess the flexibility to fulfil the hydrogen demand (ID5). The federal government adjusted all existing instruments and will create new instruments to maximally support research and innovation of hydrogen technologies. Start-ups and SMEs need support to develop new technologies (e.g., catalysts), on the other hand, developers are sufficiently supported (ID2). Green hydrogen is still a burden as wind and solar profiles have a limited output (ID2, ID5, ID7). Due to RED III criteria, RFNBO hydrogen will never be produced in Belgium (ID5). The Belgian hydrogen production is dominated by SMR from fossil methane. Besides this production method, the government is exploring low-emission hydrogen such as Auto-Thermal Reforming (ATR), the use of CCS (never 100% captured), biogas/methane and hydrogen as a byproduct from rest warmth. The use of nuclear power is an option for a CO_2 emission-free stable baseload of hydrogen (ID3, ID6, ID7). Energy diversification is needed to have flexibility, storage capacity, energy efficiency and risk spreading (ID5, ID7).

Hydrogen Deployment

The Belgian federal government identified 4 sectors where hydrogen will help to become climate-neutral by 2050 namely, as raw material in the industry for chemical processes, transportation, building environment and grid flexibility. Adding renewable energy to fuels by 2030 is mandatory (ID5). In the long term, green is the only right solution because it has the lowest CO_2 emissions (ID4, ID7).

Stakeholder Engagement

People are more aware of climate problems (IDs 2-7). Within the industry, there is a shared expectation electricity will not solve everything but is a needed intermediate to move to a hydrogen economy to reach the climate targets (ID2, ID6, ID7). Belgium made two platforms to collaborate and exchange knowledge, WaterstofNet and H2Hub Wallonia, which consist of many companies and form a value chain. As Belgium has no large funding capabilities, political support and a symbiosis between industry and government are desired (ID2). Only gas companies were investigating hydrogen and now more players have emerged and cooperation is growing (ID4). The federal government want to support and strengthen companies located in Belgium and research institutes by using instruments to engage R&D on hydrogen and derivatives. Developing the hydrogen value chain efficiently requires collaboration between involved parties. Therefore, the consultation group ENOVER/CONCERE was founded. Other partners are part of a hydrogen ecosystem and include businesses, research institutes, universities, and environmental organisations. Participation in partnerships, projects, technological advancements and research is a must for successful collaboration. This hydrogen ecosystem can address feedback about challenges market players are confronted with. The government encourage the hydrogen ecosystem to enter into dialogue with the government but industrial stakeholders are involved too little in the decision-making of the hydrogen strategy (ID7). ID7 seemed to imply that the industry and government were pitted against each other and ID1 stated the opposite. The Belgian Hydrogen Council, a sectoral organisation, will be in charge as a moderator between the government and the hydrogen ecosystem and will promote Belgian businesses on a (inter)national level. Despite these collaboration platforms, every industrial stakeholder has their strategy and problems and should not be intervened by others (ID2, ID4, ID6). However, the industry is not individualistic as many partnerships exist while being competitors (ID2, ID3, ID6). When companies were individualistic, no projects were launched (ID4). Everyone is prepared but no one wants or dares to go all-in and this uncertainty is a foundation for collaboration (ID5).

International Collaborations

The Belgian federal government are making partnerships on an international level with countries that share a mutual vision and/or goal by signing Memoranda of Understanding (MoU). Belgium wants to become an import hub for renewable molecules. The Belgian Hydrogen Council has to put Belgium on the map and be the entrance gate for renewable molecules in Europe. To become the import Hub, Belgium identified three different import routes towards Belgium. The first route is the North Sea Route where green hydrogen is generated by off-shore wind energy and transported by pipelines, this will be an agreement with countries of the North Sea. This collaboration will take place through various forums such as the North Sea Energy Cooperation (NSEC). Also, the declaration of Esbjerg is, besides an objective, an international cooperation to create a green energy power plant from the North Sea in Europe. Special attention is also offered to the partnership with the UK and Norway since Belgium has already connected gas pipelines. To maintain these partnerships, Belgium wants to support them with access to the energy carriers of the future such as green hydrogen. The second route is the Southern route where the import of hydrogen is provided by pipelines from southern regions such as the Iberian Peninsula and Northern Africa. The Southern Route is a long-term solution for the import of green hydrogen. The final route is the Shipping Route where green hydrogen will be produced in countries with plenty of sun, wind or hydropower and imported to Belgium by ship. This is why Belgium signed a MoU with Oman and Namibia. The federal government supports project launching and facilitates contacts with other countries to develop a network (ID2). Government-to-government relations with other countries are important regarding the import of hydrogen (ID2, ID4, ID5, ID6, ID7).

4.1.2 The Netherlands

Policy Objectives

The Netherlands wanted to scale up the electrolysis capacity to 500 MW by 2025 and 3-4 GW by 2030. Still, importing hydrogen is crucial as local production in the Netherlands will be too expensive (ID10). There is a lot of commitment from smaller businesses with small electrolysis capacity and adding all these businesses offers a significant and country-spread amount of capacity (ID8). Furthermore, the Dutch strategy mentioned explicitly hydrogen targets in the transportation sector. These targets consist of 15,000 fuel cell vehicles and 3000 heavy-duty vehicles by 2025 and 300,000 fuel cell vehicles by 2030. A negotiated Sustainable Aviation Agreement was committed to reach a blending of 14% of sustainable fuels by 2030 and 100% by 2050. All targets stated by the government are theoretically achievable but will come at a huge cost, therefore, 500 MW by 2025 is unachievable and some interviewees had doubts about the 4000 MW target by 2030 (ID9, ID11). There is a learning period but after 2030, the requirements become stricter (ID12). Government and industry expect the hydrogen backbone to be available and accessible by 2030 but the development of the hydrogen backbone will be delayed (ID9).

Financial Instruments and Funding

In the Netherlands, the Energy Innovation Demonstration Scheme (DEI+) encourages innovative pilot projects and applied research in the hydrogen field. To facilitate scaling-up projects, the Climate Budget funds temporary operating costs. Electrolysis projects avoid CO_2 emissions and are eligible for the SDE++ subsidy scheme where a subsidy is given per avoided tonne of CO_2. However, green hydrogen projects compete with all CO_2-mitigating projects (ID9). Regarding the transportation sector, subsidy schemes were developed for heavy-duty transport and urban logistics with zero emissions within the National Climate Agreement. On the other hand, there is a notion the new government will possibly remove the tax on fuels (ID12). The government subsidises technology through MOOI (Mission-oriented Research, Development and Innovation) tenders focusing on R&D of hydrogen production. The multi-year mission-driven innovation programmes (MMIPs) focus on subsidising innovations related to the production and application of green hydrogen in electricity and industry sectors. Some interviewees received CAPEX subsidies (ID12, ID13). From a European level, the IPCEI subsidy was given to certain projects but none of the businesses made an FID despite billions of euros given (ID9). Also, the auction by the Hydrogen Bank was won by Nordic regions and Iberia due to their low levelised cost of hydrogen (LCOH) (ID10). The investments are for the hydrogen developing side (production) but not on the customers' side (ID9, ID10, ID13). Subsidising the customers' side is insufficient to make green hydrogen cost competitive with natural gas (ID9). The lack of demand caused a lack of FIDs and more FIDs will be undertaken if there is enough support and certainty of consumption (ID10, ID11). The government is continuously in conversation with industrial stakeholders to adjust the instruments according to their demands (subsidies, purchasing obligations, etc.) (ID8).

Regulatory Frameworks and Non-Financial Incentives

The National Climate Agreement addressed several opportunities for innovation, upscaling and cost reduction. Regarding legislation and regulation, firstly, hydrogen adoption is promoted as the existing gas grid can be occupied to transport and distribute hydrogen. The regulation of the future hydrogen market and the future role of Gasunie will be examined by the government.

Statutory and regulatory flexibility can be generated and facilitate experiments, enabling regional and national network operators to gain experience in hydrogen distribution and transport. However, regulations and laws are the biggest bottleneck to integrate hydrogen (ID13). Certification and Guarantees of Origin (GOs) are required to have a reliable system to facilitate zero-carbon hydrogen in the market. A framework for GOs is already provided in RED II. Secondly, an important standard is safety. The Hydrogen Safety Innovation Programme proposes policies and agreements to address safety issues. In general, most people are positive about hydrogen and its safety (ID11, ID12), but not everyone is well informed because of inaccessible information about hydrogen (e.g., entrepreneurs in horticulture) (ID13). Acceptance of hydrogen is important as companies heavily relying on gas have to completely switch their operations and these companies can move away from Europe because there is no availability to decarbonise (ID9). Thirdly, the Main Energy Infrastructure Programme is in charge of effectively coordinating the hydrogen grid and embeds space for electrolysers, capacity, electricity infrastructure and proximity to gas infrastructure. Initiatives to combine locally produced renewable energy with green hydrogen were made to resolve and prevent grid congestion. Green hydrogen is available in low quantities, but EU regulations make it difficult to emerge (ID10, ID11). The lack of a level playing field makes green hydrogen unattractive (ID10). However, there is a belief that the hydrogen value chain can work and gain profit (ID11, ID12). For mobility, agreements between stakeholders should enhance the roll-out of hydrogen. The blending obligation of green hydrogen in the natural gas grid and aviation fuels in 2023 offered more security to green hydrogen projects. With clarified market rules and reduced costs of green hydrogen, there is a clear picture for customers on how hydrogen can reach sustainability in their operations. The ETS system is an incentive to move to green hydrogen but it will take a while before green hydrogen will become competitive (ID10). Europe should obligate consumers to buy products with a low-carbon footprint and the cost of green hydrogen in products should be moved to a different place within the value chain and preferably towards the end consumer (ID11). Fossil-based hydrogen will still exist because of RED III as this makes the production of RFNBO hydrogen ambitious or even not achievable (ID9, ID11). The rules of RED III should be weakened (ID12). However, the Netherlands has clear plans for RED III implementation (ID11). A reduced RFNBO target in RED III has to make sure the industry will stay (ID8). Within the context of hydrogen, an analogue to the renewable energy units (HBEs) can be developed as this could stimulate the consumption of hydrogen or decarbonise industrial operations (ID10). It is important to roll it out on a European level, otherwise, no level playing field is available (ID10). Sufficient initiatives exist but a legislative framework is still missing (ID8).

Hydrogen Production and (Innovative) Technology

Innovation can increase the efficiency of the electrolysis process, leading to lower costs as people are concerned about efficiency (ID10). Research is still required to search for cheaper materials for membranes and electrodes. Also, the technology to link off-shore wind energy and hydrogen in the North of the Frisian Islands will be reviewed. To connect knowledge about chemistry, high-tech manufacturing and energy, the Electrochemical Conversion & Materials (EECM) programme was established. From the government's perspective, small-scale and large-scale production is available by low-emission hydrogen production. The periods without sun or wind will be replenished with the import of grey hydrogen as this will always play a role but the role will diminish because of ETS (ID9, ID10). Therefore, blue hydrogen is desired as a path toward green hydrogen (ID10, ID11). This is indicated by two blue hydrogen projects

(Porthos and H-Vision). The production of blue hydrogen is not obvious for the Netherlands, Norway has better facilities to produce blue hydrogen which can enable a stable supply, but the current grid congestion paves a path for blue hydrogen as this competes with electrolysers (ID11, ID12). Still, the governmental strategy states that blue hydrogen offers a path for large-scale green hydrogen. Nuclear energy could also solve intermittency (ID11, ID12). However, experience regarding the production of green hydrogen and its application in several sectors in the Netherlands will result in cost reductions and an improved understanding of the market size.

Hydrogen Deployment

Clean hydrogen consumption in gas plants can deliver sustainable flexibility in the power capacity. The deployment of hydrogen will be in the industry and ports, the transport sector, the building environment and the electricity sector. The first application to adopt green hydrogen is the fuel sector due to the blending obligation (ID10). The energy mix within horticulture will be dynamic and fossil fuels will be a part together with e.g., rest warmth, biomass, etc. depending on time and location (ID13). There is awareness about hydrogens' role of as a solution to get rid of fossil fuels and the lack of alternatives for some sectors (ID10). On the other hand, there is more realism about green hydrogen and the associated challenges (ID11). In the long term, green hydrogen will be the best option (ID11, ID13).

Stakeholder Engagement

Businesses and knowledge institutions should invest in innovation and research of scalable applications, while the government should focus on meeting the necessary preconditions. Businesses are acting individualistic, only a few parties can perform research and are indirectly responsible for sharing knowledge (ID9, ID13). None wants to take the initiative since early adopters will pay the biggest costs (ID10). Everybody has their issues, however, there is some contact between consumers (ID10, ID13). Universities and research institutes are currently collaborating on the hydrogen value chain. The government addressed zero-carbon hydrogen in announced projects as crucial for companies in the Netherlands. It will enable these companies to switch to clean hydrogen and form industry clusters. The climate crisis makes us more aware (ID11, ID13). The government is doing their best but takes decisions slowly (ID10, ID11, ID12). Decision-making takes often 2 years and is impossible to align with the pace of the market (ID8). The Dutch government claims the responsibility for infrastructure but the supply is left to the market and regarding the cost of green hydrogen, it is questionable if a network could emerge (ID13). Hydrogen supply chains are vital for the Dutch economy and hydrogen clusters are developing (e.g., Hydrogen Valley in the North of the Netherlands). NL Hydrogen is a network of producers and consumers that can share a lobbying perspective toward the EU and the Netherlands to reach the targets (ID10, ID11, ID12). On a smaller scale, SMEs, municipalities, citizens, etc. are collaborating on innovative hydrogen applications with an integrated approach. Despite this, electrolyser companies have difficulties with collaboration because of intellectual property protection (ID11). Regarding the policy agenda, the usage of the gas network will be reviewed by the government and network operators/companies. Local/Regional authorities will be essential in supporting decentralised solutions and offering flexibility for projects, with regional policies as a significant factor. Regional authorities and organisations want to involve citizens in the energy transition. Regarding RED III, the government organises consultation sessions about the implementation of RED III. There is a lot of dialogue but no execution of projects (ID12). An underestimated aspect is the balance of different interests as you cannot please everyone (ID8). Interest groups have the feeling of not being heard enough (ID8)

International Collaboration

The Netherlands believes cost savings will be achieved in a European or international context. Especially, the Dutch government want to align their hydrogen vision with countries and regions in Northwest Europe, their potential sales market. The European programme Horizon 2020 is considered an important partnership for Dutch companies and knowledge institutions. The Dutch strategy involves an international strategy with a focus on Europe. The first track is the engagement with the European Commission at all possible levels. The second track is about the Netherlands, along with Austria, initiating the development of common approaches to market incentives/regulations and standards at a Pentalateral Forum consisting of the Benelux, France, Germany, Austria and Switzerland. The third track compromises collaborations with North Sea Countries e.g., North Sea Wind Power Hub project between the Netherlands, Denmark and Germany about off-shore wind energy for green hydrogen production. The fourth track consists of bilateral cooperation with neighbouring states. An example is the HY3 project between Germany and the Netherlands to provide green hydrogen through Dutch gas pipelines to feed Dutch and German industries. The final track is the IPCEI where Dutch projects can apply but collaboration with another Member State from the EU is required. The Netherlands remarked a notable interest from foreign companies in hydrogen projects in the Netherlands. Therefore, bilateral agreements will be made with net exporting countries of clean hydrogen (e.g., Portugal).

4.1.3 Strategy Comparison by Policy Advisors

The policy advisors (ID1 and ID8) and the NGO interviewee (ID7) that were interviewed gave insights about the differences between the government strategies. This is covered in a separate paragraph since these insights are not covered in the governmental strategies but are relevant to address and discuss later.

The strategies of both countries are similar (ID1, ID8), but several differences can be noted. The first big difference is the higher potential of local green hydrogen production and a less strong focus point on import in the case of the Netherlands (ID1). Another difference is the international approach, the Netherlands signed a lot of bilateral agreements with third parties outside Europe to develop a fast value chain of hydrogen imports and on the other hand Belgium has a limited amount of partnerships because the government want to focus on small partnerships and go as far as possible with these collaborations and use the resources as efficient as possible (ID1). Also, the Netherlands has more money to support green hydrogen development and a less complex governmental structure with more power (ID7, ID8). A cultural difference can be seen as Belgium is more modest regarding its targets and the Netherlands communicates more and sets ambitious targets (ID7). ID8 stated the Netherlands is earlier with their strategy and focuses now on hydrogen carriers and is ahead of Belgium, meanwhile, ID7 stated the hydrogen technology is better in Belgium.

4.2 Impact of Green Hydrogen Niche

The green hydrogen niche will have an impact on the manufacturing regime by reducing the CO_2 emissions from the hydrogen feedstock and the energy regime by substituting fossil fuels with corresponding CO_2 reduction. As earlier mentioned, green hydrogen is expensive compared to conventional hydrogen production methods. The production of renewable electricity faces intermittency and a stable baseload is required for the manufacturing industry. On the other hand, the energy regime offers opportunities for hydrogen to reduce the carbon footprint of industrial processes and competition exists with other energy sources. Also, RED III forces these regimes to consume green hydrogen. The following paragraphs will address the expectations of the interviewees regarding the impact of green hydrogen on the predefined regimes.

4.2.1 Manufacturing Regime

Belgium

In the hydrogen strategy, the federal government identified the industry as one of the most desired sectors to develop the hydrogen demand and it is expected to increase. Hydrogen is an important resource for several chemical processes. Electrification is the first step in the industry but hydrogen used as feedstock cannot be electrified (ID2). The chemical industry is currently consuming the largest amounts of hydrogen and should be the first focus point (ID1, ID2, ID3, ID4, ID5, ID7). Green hydrogen is needed to avoid grey hydrogen used nowadays (ID4). In the chemical manufacturing industry, a large consumer of hydrogen is the ammonia-based fertiliser industry where grey hydrogen has to be substituted (ID2, ID5, ID6). Fertilisers can also be made by other methods but historically it is ammonia-based and green hydrogen is a solution, but blue hydrogen is needed as a transition technology before switching to green hydrogen due to high costs (ID2). Also, the refineries can green their operations by using green hydrogen, which seems strange to decarbonise the production of fossil fuels (ID2, ID7). Half of the hydrogen volume comes from grey hydrogen and has to be substituted by green hydrogen because of RED III (ID5). Due to RED III, green hydrogen will have an impact on the fuel sector due to the blending obligation with renewable molecules (ID5). The steel industry can use green hydrogen to reduce iron oxides and decarbonise operations (ID2, ID3, ID4). The products made of green hydrogen will be expensive now and the end consumer does not want to pay (ID4). Therefore, blue hydrogen is needed to make an affordable product to the consumer and this scale-up will enable green hydrogen (ID4).

The Netherlands

The manufacturing industry has been mapped in the area of hydrogen by the Dutch employers' organisation because the Netherlands has many companies in the manufacturing industry with the potential to become key players within the hydrogen economy. Hydrogen has been used as feedstock for a long time. Regarding the manufacturing regime, green hydrogen is the best substitute for grey hydrogen in feedstock for the chemical industry in the long term as with the ETS it will last several decades before it will be competitive (ID9, ID11, ID12). The first sector taking up green hydrogen will be the refineries because of the blending obligation (ID8, ID10). Fertiliser companies will consume green ammonia coming from green hydrogen but the end consumer will pay the cost (ID10, ID11). If the fertiliser industry chooses to import ammonia, then no one will build an electrolyser in the Netherlands (ID8). In the steel industry, second-hand steel needs electricity but the consumer desires virgin originating from coal or (green) hydrogen-based steel that will be present in the future (ID11, ID12). Also, refineries can use green hydrogen to reduce the CO_2 footprint of their operations instead of fossil-based resources (ID10, ID12). All manufacturers want a stable supply of green hydrogen which is challenged due to the intermittency of green electricity (ID11). Therefore, blue hydrogen is desired as a transition phase toward green hydrogen (ID10, ID11).

4.2.2 Energy Regime

Belgium

By burning hydrogen, high temperatures can be reached which justifies, according to the strategy, the use of hydrogen in the production of e.g., concrete or glass. Probably, the demand for renewable molecules in the industry sector will increase as sustainable alternatives to fossil fuels. Electrification will always be the priority (ID1). At the moment, there is a low consumption of hydrogen for the decarbonisation of industry as this will be conducted in a second phase after the feedstock (ID4). However, the energy regime will be developed like the manufacturing regime (ID1). Companies are seeking to use hydrogen for heating purposes but it is debatable when electrification is not suitable anymore (ID7). Hydrogen for heating processes will be possible but the preference is to capture the CO_2 after burning natural gas (ID5). Process heating with hydrogen will come from the chemical reaction heat of hydrogen as feedstock (ID2). Hydrogen as a thermal resource is less interesting, better alternatives exist such as heat pumps (ID2). RED III impacts the energy mix by obligating to blend renewable molecules such as green hydrogen within the fuels (ID5). Green hydrogen can store an oversupply of green electricity, absorb fluctuations in the electricity grid and avoid grid congestion (ID1, ID5, ID7). Moreover, complete dependency on other countries is avoided by not using batteries and critical raw materials. Green hydrogen can increase the flexibility of the energy system (ID7).

The Netherlands

The Dutch strategy mentioned the use of a zero-carbon gas (e.g., hydrogen) to produce high temperatures in industry. The peak load of heat pumps or heat grids can be supplied with hydrogen. Hydrogen was pointed out as suitable for many applications but electrification and the use of heat pumps are considered better instead of burning hydrogen for heating purposes (ID8, ID9, ID11). Industries cannot be forced to use hydrogen when electricity is also a suitable option (ID10). But theoretically, if green hydrogen is cheap, it can be used to heat industrial and chemical processes instead of natural gas (ID8, ID12). Within horticulture, the application of hydrogen is only for heating purposes to absorb peaks (ID13). Horticulture is not seen as a prioritising sector to supply hydrogen and is not realistic to supply sufficient hydrogen for consumption in the first 10 years in the horticulture sector (ID13). In the steel industry, the ovens can be heated up with e.g., blue hydrogen instead of natural gas which will reduce CO_2 emissions but RED III obligates to consume partly green hydrogen (ID10). When there is an oversupply of renewable electricity, green hydrogen should be a solution as batteries have a short lifespan (ID8, ID12). This increases the flexibility and variability of the supply of the energy system as well as the avoidance of switching off windmills or solar panels because of overproduction (ID12). Regarding horticulture, the varying hydrogen demand is a weak spot, but horticulture can play a role in balancing the different energy streams and absorbing the surplus of energy or supply in case of a shortage (ID13).

Chapter 5 Discussion

Within this chapter, the Results will be discussed. First, the empirical findings from the strategies and interviews will be classified according to the SNE framework and discussed. Afterwards, the pathways envisioned by the government and the interviewees will be addressed, leading to an answer to the first subquestion. To answer the second subquestion, a discussion of the impact of the green hydrogen niche on the predefined regimes will be executed. The Discussion chapter will end with a reflection on the limitations.

5.1 Governmental Comparison

5.1.1 Effective Niche Protection

Tables (3-6) present an overview of the SNE aspects applicable to the themes within the strategy of Belgium followed by the industrial stakeholders' perception of Belgium and the Netherlands respectively. This classification was based on empirical indicators from the literature (Verhees et al., 2015; Raven et al., 2016; Smith & Raven, 2012). The industrial stakeholders' perception Tables distinguished between ongoing SNE aspects and remarks about the corresponding SNE aspect indicating a defect or proposal.

Table 3. Overview of SNE aspects in the Belgian hydrogen strategy

Theme	Shielding	Nurturing	Empowerment
Policy Objectives	-	▪ Electrolysis capacity up to 150 MW by 2026 ▪ Off-shore wind capacity up to 5,4-5,8 GW by 2030 (potentially up to 8 GW) ▪ 100-160 km pipelines by 2026 connected to neighbouring countries by 2028 ▪ Esbjerg Declaration ▪ Hydrogen import of 20 TWh by 2030 and 200-350 TWh by 2050	-
Financial Instruments and funding	▪ Clean Hydrogen for Clean Industry ▪ Energy Transition Fund ▪ Support VKHyLab ▪ Funding to accelerate interconnection with Germany ▪ Funding scheme for 100-160 km pipeline ▪ Exemption from excise duties on electricity ▪ Call for Import of Hydrogen	-	-
Regulatory Frameworks and Non-financial Incentives	-	▪ Support European partners by pipeline with energy carriers ▪ European market creation ▪ Safety regulations for transport of gaseous products by pipeline	▪ Only renewable hydrogen will have a share in energy mix before 2050

		▪ Memoranda of Understanding ▪ European market regulations and certification norms ▪ Transparency and trust measures (e.g., certification) under supervision of CREG	▪ Natural gas networks for hydrogen
Hydrogen Production and (Innovative) Technology	-	▪ Minimal electrolysis capacity for expertise and credibility ▪ Exploration of low-emission hydrogen production ▪ Technologies for injecting hydrogen into transportation networks	-
Hydrogen Deployment	-	-	-
Stakeholder Engagement	-	▪ Exchange knowledge through collaboration platforms ▪ Belgian Hydrogen Council as moderator between government and stakeholders ▪ Consultation group ENOVER/CONCERE to facilitate collaboration among involved parties ▪ Push of government to business and research institutes to develop technologies and research on hydrogen and derivatives	-
International Collaboration	-	▪ Memoranda of Understanding ▪ Positioning as international import Hub ▪ North Sea Energy Cooperation and Esbjerg Declaration: green energy generation ▪ Pipeline network development to UK and Norway and neighboring countries ▪ European Hydrogen backbone from Spain	-

Table 4. Overview of SNE aspects in industrial stakeholders' perception of Belgium

Theme	Shielding	Nurturing	Empowerment
Policy Objectives	-	*Ongoing: /* *Remarks* ▪ Missing timeframe and speed of reaching targets	-
Financial Instruments and funding	*Ongoing* ▪ Subsidies from Europe ▪ Klimaatsprong ▪ CAPEX support ▪ Support for developers ▪ Subsidies for energy companies *Remarks* ▪ Hydrogen Bank budget not sufficient ▪ Lack of OPEX support ▪ Federal financial support neglectable ▪ Funded green hydrogen projects but barely realized ▪ No support downstream hydrogen value chain ▪ Mechanisms for price increase fossil-based hydrogen (tax, penalties) ▪ Make non-climate-neutral products more expensive ▪ Penalising failure in RED III and adjustments subsidy RFNBO hydrogen ▪ Few FIDs due to uncertainty	-	-
Regulatory Frameworks and Non-financial Incentives	-	*Ongoing* ▪ Blue hydrogen as transition phase ▪ Criteria and regulations when hydrogen is considered green *Remarks* ▪ Alignment with fossil fuels ▪ Different views on social barriers ▪ Criteria and regulations to prove hydrogen is green ▪ CO_2 footprint instead of colours	*Ongoing* ▪ Agenda 2025 ▪ RED III ▪ ETS ▪ CBAM *Remarks* ▪ Obligation to buy low-carbon products ▪ Industrial Deal ▪ RED III too much focus on green hydrogen ▪ Adjustment of criteria RED III ▪ Translate RED III homogeneous in local regulations

Hydrogen Production and (Innovative) Technology	-	*Ongoing:* / *Remarks* ▪ Local production cancelled ▪ Support start-ups and SMEs for new technologies	*Ongoing:* / *Remarks* ▪ No RFNBO hydrogen production
Hydrogen Deployment	-	*Remark* ▪ Focus on green hydrogen in long term	*Ongoing* Mandatory addition of renewable energy into fuels
Stakeholder Engagement	-	*Ongoing* ▪ Climate awareness ▪ Symbiosis government-industry ▪ Exchanging knowledge and visions through collaboration platforms ▪ Growing cooperation ▪ Government-to-government ▪ Partnerships *Remarks* ▪ Little involvement of industry in decision-making ▪ Industry vs government	-
International Collaboration	-	-	-

Table 5. Overview of SNE aspects in the Dutch hydrogen strategy

Theme	Shielding	Nurturing	Empowerment
Policy Objectives	-	▪ Electrolysis capacity up to 500 MW by 2025 and 3-4 GW by 2030 ▪ Target for sustainable aviation fuels (14% by 2030 and 100% by 2050) ▪ 15 000 fuel cell vehicles and 3000 heavy-duty vehicles by 2025 and 300 000 fuel cell vehicles by 2030	-
Financial Instruments and funding	▪ DEI+ subsidy ▪ Climate Budget ▪ Transport sector subsidy ▪ IPCEI (EU) ▪ MOOI subsidy ▪ MMIP ▪ SDE++	-	▪ SDE++
Regulatory Frameworks and Non-financial Incentives	▪ Statutory and regulatory flexibility for network operators	▪ Hydrogen Safety Innovation Programme ▪ Main Energy Infrastructure Programme: coordination of hydrogen grid and integrating electrolysers ▪ National Climate Agreement ▪ Agreements with stakeholders about mobility ▪ Clarifying market rules and costs of green hydrogen ▪ Future role of Gasunie ▪ Grid congestion initiatives: combining locally produced renewable energy with green hydrogen ▪ Certification and Guarantees of Origin (EU)	▪ Blending obligation ▪ Promoting the usage of existing gas grid for hydrogen transport
Hydrogen Production and (Innovative) Technology	▪ MOOI ▪ MMIP	▪ EECM programme ▪ Exploration of low-emission hydrogen production ▪ Market size understanding ▪ Research on membranes and electrodes ▪ Technology to couple green hydrogen production to off-shore wind energy	-
Hydrogen Deployment	-	▪ Clean hydrogen in gas plants for flexibility in power capacity	-
Stakeholder Engagement	▪ Collaboration between market participants and network operators	▪ Hydrogen clusters ▪ Collaboration between SMEs, municipalities and citizens	-

		▪ Collaboration between universities and research institutes ▪ Promoting businesses and knowledge institutions to invest in technological innovation and research ▪ Involvement of citizens within energy transition ▪ Review of usage of gas network	
International Collaboration	-	▪ North Sea Wind Power Hub ▪ Engagement with EC at all possible levels ▪ Pentalateral Forum ▪ Horizon 2020 (EU) ▪ Attracting international projects ▪ Bilateral HY3 project ▪ IPCEI	-

Table 6. Overview of SNE aspects in industrial stakeholders' perception of the Netherlands

Theme	Shielding	Nurturing	Empowerment
Policy Objectives	-	*Ongoing* ▪ Learning period until 2030 *Remarks* ▪ Cheaper to import hydrogen ▪ Targets unachievable ▪ Delay of hydrogen backbone	-
Financial Instruments and funding	*Current Shielding* ▪ CAPEX subsidies ▪ Subsidies from Europe ▪ SDE++ *Remarks* ▪ Possibility to remove tax on fuels ▪ Hydrogen Bank (EU) tender won by countries with low LCOH ▪ IPSEI (EU) but no FID ▪ Investment only on developing side ▪ More FIDs when enough support	-	*Ongoing* ▪ SDE++ *Remarks* ▪ No RFNBO hydrogen production
Regulatory Frameworks and Non-financial Incentives	-	*Ongoing* ▪ Hydrogen acceptance *Remarks* ▪ Information inaccessible for entrepreneurs in horticulture ▪ Mixed visions about safety of hydrogen ▪ Lack of playing field	*Ongoing* ▪ ETS ▪ RED III ▪ Plans for RED III implementation *Remarks* ▪ Analogue to HBEs ▪ Move obligation to another place in the supply chain ▪ Obligation from EU to buy low-carbon footprint products. ▪ Fossil-based hydrogen still has a share due to RED III ▪ Adjustment of criteria RED III ▪ RFNBO Criteria do not allow blue hydrogen
Hydrogen Production and (Innovative) Technology	-	*Ongoing* ▪ Blue hydrogen as transition phase	*Remarks* ▪ No RFNBO hydrogen production
Hydrogen Deployment	-	*Ongoing*	*Ongoing* ▪ Blending obligation

		▪ More realism about green hydrogen *Remarks* ▪ Focus on green hydrogen in long term	▪ Dynamic energy mix
Stakeholder Engagement	-	*Ongoing* ▪ Government responsible for infrastructure ▪ Climate awareness ▪ Market responsible for hydrogen supply ▪ NL Hydrogen ▪ Consultation sessions about RED III implementation ▪ Government-to-government ▪ Partnerships *Remarks* ▪ Little involvement of industry in decision-making ▪ Industry vs government	-
International Collaboration	-	-	-

Effective protection of the niche has to possess three properties: shielding, nurturing and empowerment (Smith & Raven, 2012). All three properties could be identified in the governmental strategies and the interviews with the industrial stakeholders. Regarding the strategies of both countries, the most identified elements are nurturing aspects. The dominance of nurturing aspects is not surprising as hydrogen and the hydrogen economy kicked off slowly in the ’70s and exist already more than 50 years (Yap & McLellan, 2023). During the oil crisis, alternative technologies were investigated such as green hydrogen (Yap & McLellan, 2023). Therefore, green hydrogen is not particularly new and the strategies indicate a shift away from pure shielding, as nurturing is about improving the performance of the shielding innovation and early research efforts apply to a lesser extent (Verhees et al., 2015).

Financial instruments and funding are mainly covered in the shielding columns. Mostly subsidies are provided to shield the green hydrogen niche which are European and national subsidy schemes (Verhees et al, 2013). The Belgian government lacks budgetary leverage so the funding schemes are considered neglectable compared to the European financial instruments, making Belgium heavily rely on European instruments and indicating a more centralised approach. The Netherlands has more funding capabilities but there is a consensus among the industrial stakeholders about insufficient funding on both national and European levels. Moreover, the industrial stakeholders of both countries point out the lack of funding and support as a reason for little FIDs. In general, there are shielding initiatives in the strategies and mentioned by the industrial stakeholders for green hydrogen but the support is insufficient to develop a hydrogen economy within the industry. To add upon, a misallocation of shielding measurements can be detected due to the lack of shielding on the demand side and OPEX.

Shielding creates space for niches and an opportunity to nurture the green hydrogen niche within the space created (Smith & Raven, 2012; Verhees et al., 2013). Regarding the nurturing aspects, both countries stated several policy objectives and focused on regulatory frameworks and non-financial incentives in order to aim for shared expectations and organising learning processes respectively (Verhees et al, 2015). In the **policy objectives**, the electrolysis capacity target of the Netherlands is more ambitious due to the higher local renewable energy potential, indicating a more decentralised approach. This offers flexibility for green hydrogen despite the high costs of local production. Belgium also will face a low amount of electrolysis capacity to diversify and to create credibility and expertise for their technologies, but Belgium is more focused on electrification and green hydrogen import and as such the electrolysis capacity target is low, so the ambition can be higher. The need for clear targets is important to avoid ignorance or cancelling of the implementation (Moore, 2018). The nurturing requirement for learning processes of the green hydrogen niche is visible in the **regulatory framework and (non)financial incentives** theme within the strategies and the perspectives of the industrial stakeholders in the sense of safety (Smith et al., 2014). Both strategies mentioned regulations or programmes regarding the safety of hydrogen. These initiatives are beneficial in creating shared expectations since the industrial stakeholders have different viewpoints about the safety and acceptance of hydrogen. Regarding **stakeholder engagement**, both governments support initiatives to explore technologies and exchange knowledge through collaboration platforms or industrial clusters. The Dutch government seems more proactive in informing the industry about new laws and regulations and how to implement these compared to the Belgian government. Transparency and the creation of trust are an important aspect regarding the classification of green hydrogen as both strategies and industrial stakeholders mentioned this. Another focus point within **stakeholder engagement** is to develop a hydrogen ecosystem and exceed national borders by committing to international collaborations. These nurturing elements can offer shared expectations and the formation of deep and diverse networks (Verhees et al, 2015). Both strategies emphasise the formation of collaboration platforms and clusters to address and discuss common concerns and viewpoints of the industrial stakeholders. These social platforms and clusters can facilitate the development of the green hydrogen niche and the construction of social networks is a nurturing requirement (Schot & Geels, 2008). The consultation sessions about laws and regulations are appreciated by the industrial stakeholders in the Netherlands. This enhanced communication can facilitate more public-private partnerships. In Belgium, the viewpoint of industrial stakeholders is that there is too little involvement of industrial stakeholders in decision-making despite the existence of collaboration platforms. Belgium has a complex political structure compared to the Netherlands consisting of multiple layers of government with divided power and responsibilities. Therefore, decision-making processes are slowed down since coordination and alignment are needed between the authorities. However, this fragmentation allows diverse approaches suitable for each regional preference or strength. The Dutch government is less complex and generates faster decision-making. Improving collaboration between governmental and industrial stakeholders is needed for robust and shared expectations to build a successful niche (Schot & Geels, 2008). Remarkably within the **hydrogen production and (innovative) technology** theme is the role of blue hydrogen. Both strategies mentioned blue hydrogen as a possible transition phase towards green hydrogen. In the Netherlands, this is endorsed by a series of announced blue hydrogen projects. Belgium is rather negative about blue hydrogen by the statement that it is impossible to capture 100% of all CO_2 emissions with CCS but there is no significant contestation against blue hydrogen. The industrial stakeholders made clear that blue hydrogen is needed to establish a green hydrogen market. Broadly, this emergence of a shared blue hydrogen perspective is an empirical indicator of nurturing and aims to improve the economic performance of the green hydrogen niche (Verhees et al., 2015). On a technological level, the Netherlands evaluate the connection between wind energy and hydrogen production facilities. The establishment of an import and transit hub is the technological approach of Belgium while ensuring the strategy is aligned with the EU policies. The perspectives of both countries aid in ensuring hydrogen strategies are robust and aligned with broader economic and sustainability objectives. In the long term, the focus is green hydrogen as stated in the **hydrogen deployment** theme. Regarding the import role both countries want to achieve in an **international collaboration** context, the formation of international agreements is important. Belgium is more focused on a limited amount of partnerships and putting maximum effort out of this whilst the Dutch strategy is more focused on signing multiple bilateral agreements to elaborate a fast hydrogen supply chain with clean hydrogen exporting countries. Belgium has a higher dependency on several countries, while the Netherlands is spreading the risk of green hydrogen dependency. In the **international collaboration** theme, only the Belgian industrial stakeholders explicitly stated the importance of government-to-government relations in accordance with the hydrogen strategy. Again, a shared expectation within social networks is a crucial requirement to succeed in nurturing (Smith et al., 2014). In general, all the key aspects of nurturing are visible within the strategies and interviews indicating a successful nurturing mindset of the green hydrogen niche. However, the industry still addressed remarks regarding nurturing for all themes except hydrogen financial instruments and funding and international collaboration. Financial instruments and funding are mainly about shielding and international collaboration was not the focus of the interviews.

The third element of successful niche protection is empowerment, which complements shielding and nurturing and is the least developed in the literature (Raven et al., 2016). In Belgium, the use of unoccupied natural gas networks indicates a reconfiguration and empowers the industry to adopt green hydrogen under the conventional selection criteria indicating a fit-and-conform empowerment. The Dutch government also promotes the use of the existing gas grid. The experience with natural gas in the Netherlands can facilitate the transition to green hydrogen, but it is not a guarantee. Furthermore, within the fit-and-conform form of empowerment, the Dutch government implemented a blending obligation of green hydrogen into the natural gas grid. This initiative can scale up the green hydrogen innovation and gradually remove the shielding (Verhees et al., 2015). This obligation applies also to the fuel sector within the industry. The last fit-and-conform form of empowerment can be found in the Dutch strategy and industrial stakeholders' perception which is the SDE++ subsidy scheme. The SDE++ incorporated electrolysis projects to be eligible for the subsidy. It encourages the green hydrogen niche to grow and increase its competitiveness with other conventional CO_2 reduction technologies under the conventional criteria (Verhees et al., 2015). An important remark is that certain instruments such as the SDE++ can affect multiple properties of the protective space since it is a subsidy scheme shielding green hydrogen niches from fossil fuel-based operations but on the other hand, it is empowering the green hydrogen niche within the CO_2 reduction technologies (Verhees et al., 2015). This validates the argument of Verhees et al. (2015) that the SNE aspects are not automatically one after the other. Looking at the other category, the stretch-and-transform type of empowerment, the statement of the Belgian government about only green hydrogen will have a place in the energy mix before 2050 is an example of the green hydrogen niche influencing the selection environment of hydrogen production and will affect the evolution of the green hydrogen niche. On a European level, the ETS and CBAM instruments were mentioned by the Belgian and Dutch industrial stakeholders which aid in redirecting the actors within the existing regime to invest in niche solutions (Smith & Raven, 2012). Also, industrial stakeholders of both countries proposed an obligation to buy low-carbon hydrogen products within Europe. This can also be classified within stretch-and-transform as this obligation would be translated into policies and institutionalised (Verhees et al., 2015). One remark is the ETS is based on the price of carbon allowances and can fluctuate, which creates uncertainty for the industry to make decisions in the long term (Brohé & Burniaux, 2015). The final interesting aspect within the stretch-and-transform empowerment is the context of RED III. In the case of hydrogen, the share of green hydrogen used for final energy and non-energy purposes should be 42% and 60% by 2030 and 2035 respectively (Directive 2023/2413). This is an obligation for all Member States and a policy that has been institutionalised and changed the existing selection criteria (Verhees et al., 2015). Green hydrogen is pushed by this directive besides other types of low-carbon hydrogen production. Within the industry, a lot of frustration can be observed regarding RED III. Especially the lack of shielding makes it difficult for industries to implement green hydrogen in their operations if no market is established. The empowerment caused by RED III tends to have the opposite effect since the industrial stakeholders can lose their sense of choice (Avelino, 2017). Also, the industrial stakeholders made clear that the targets of RED III should be weakened. A possible consequence of the (dis)empowerment of RED III, is that businesses will move outside Europe. To sum up, both forms of empowerment apply to aspects within the green hydrogen niche. However, it is possible to have unintendedly the opposite effect of empowerment which can be risked by RED III and is acknowledged by the industrial stakeholders.

The most prominent insights are inadequate shielding (misallocation and low funding) and the disempowerment of the RED III. Also, more empowerment aspects (mainly from a European level) are ongoing compared to the release of the strategies. All the key aspects of nurturing are present, but some remarks are made by the industrial stakeholders. The industrial stakeholders tend to opt for an integral approach to obtain effective protection of the green hydrogen niche. Green hydrogen has the potential to induce economic growth for both countries and aid in the desired industrial decarbonisation.

The SNE framework is adequate in identifying the degree of effective protection of the niche and is empirically validated by the results. Well-designed policies that balance SNE with continuous monitoring and revision are needed. The policies should be flexible and adaptive to respond to evolving market and technological conditions. Barriers can be addressed and overcome by effective protection. This framework has been applied to a new context within the energy transition and decarbonisation of the industry.

5.1.2 Transition Pathway

Due to the idealistic character of the innovation pathways described in the literature, the innovation pathways do not occur completely in reality and empirical cases can have aspects relating to multiple pathways (Geels & Schot, 2007; Verbong & Geels, 2010). Besides, it is even possible to shift between pathways as transitions tend to have a non-linear behaviour (Geels et al., 2016). Although some SNE elements can be classified in the other pathways, most of the elements of the strategies indicate incremental modifications by incumbent actors in response to external pressures, stricter regulations and societal debates indicating a transformation pathway (Geels et al., 2016). The reorientation of incumbent actors was visible from the responses of industrial stakeholders due to moderate landscape pressures such as the European Green Deal (Geels, 2019). This landscape pressure occurred when the green hydrogen niche was underdeveloped. Still, the whole market needs to develop and it seems that the European Green Deal is insufficient for the green hydrogen niche to take the upper hand in the existing regimes (Verbong & Geels, 2010). Complete substitution is not possible as the technology is still considered a barrier and the industrial stakeholders are not supporting completely the green hydrogen niche due to the costs and future uncertainties (Osazuwa-Peters et al., 2021). Gradual adjustments exist regarding policy objectives in both strategies which aid in a reorientation of incumbent regimes (Verbong & Geels, 2010). The current industry has to reorient its activities due to additional environmental policies (landscape pressures) such as RED III and ETS which creates additional space for the green hydrogen niche to develop (Verbong & Geels, 2010). The industrial stakeholders are not locked in as often suggested by the MLP, but citizens still desire fossil fuels which is a lock-in effect (Geels et al., 2016). All interviewees acknowledged the climate problems, the need to change current industrial operations and that green hydrogen will play a role in this narrative. The transformation pathway can be interpreted from a governmental perspective as a pathway where small improvements improve the system without radical changes but the system is never ordered as continuous readjustments are required and this makes it difficult to analyse the effectiveness of the transformation (Turnheim et al., 2015).

Depending on the perspective, it is possible to assign an element to different pathways. For example, stated goals and targets in the future in the case of hydrogen imply a transformation pathway. On the other hand, these goals and targets can also interpreted as a de-alignment of fossil fuels and a re-alignment toward green hydrogen as fossil fuels will decline and create space for green hydrogen to develop (Geels et al., 2016). All transition pathways are slightly touched upon. An example of an SNE element in each pathway envisioned by the strategies is visualised in Figures 4-7 where red, blue and green are respectively Belgium, the Netherlands and both countries.

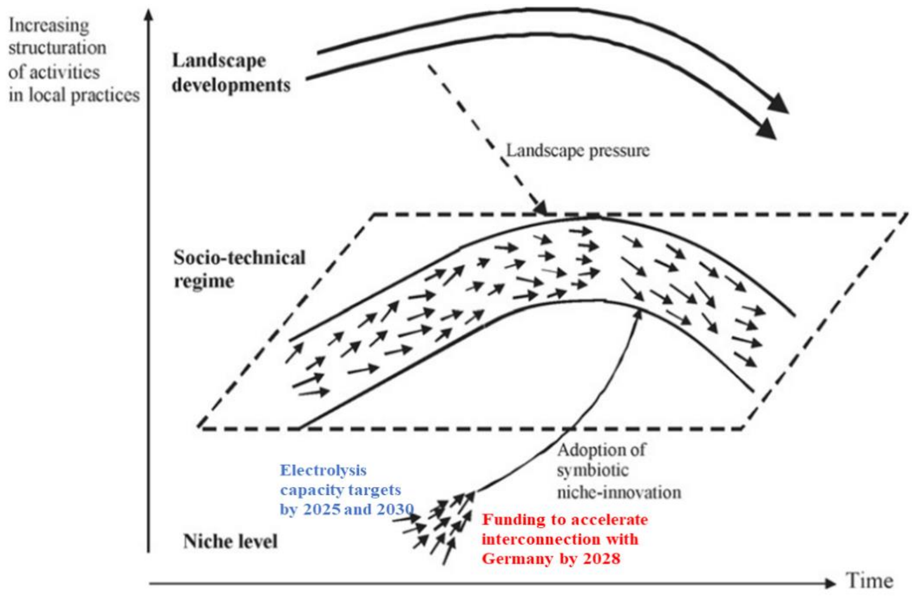

Figure 4. Transformation pathway (adapted from Geels & Schot, 2007)

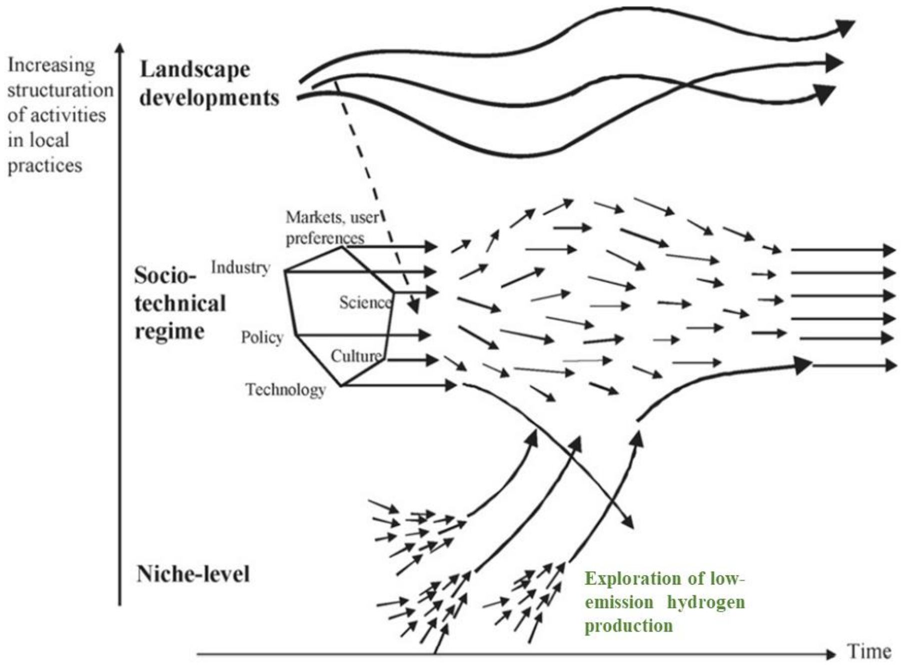

Figure 5. De- and Re-alignment Pathway (adapted from Geels & Schot, 2007)

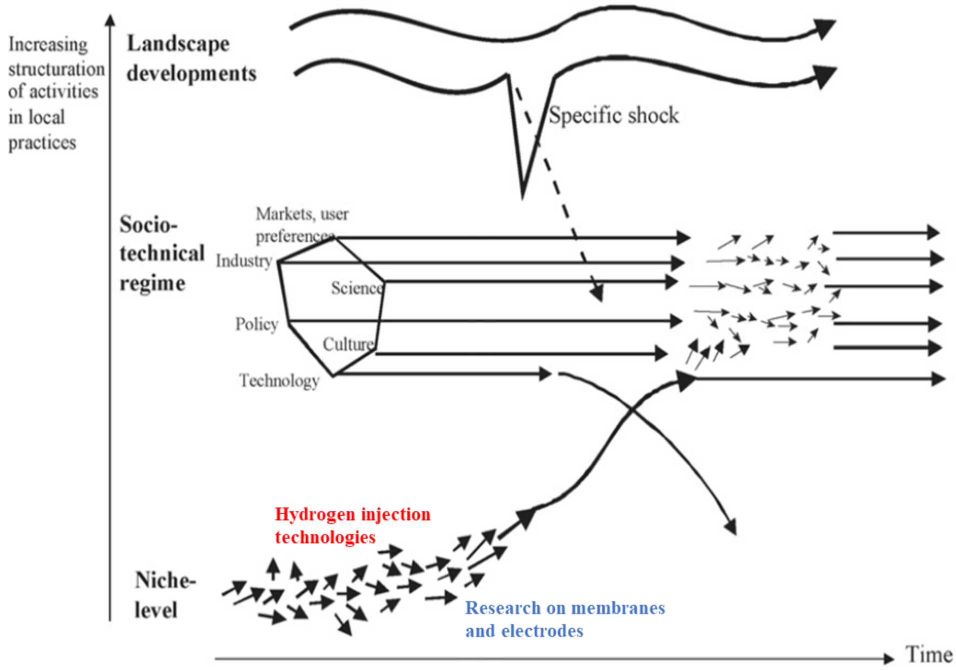

Figure 6. Technological Substitution Pathway (adapted from Geels & Schot, 2007)

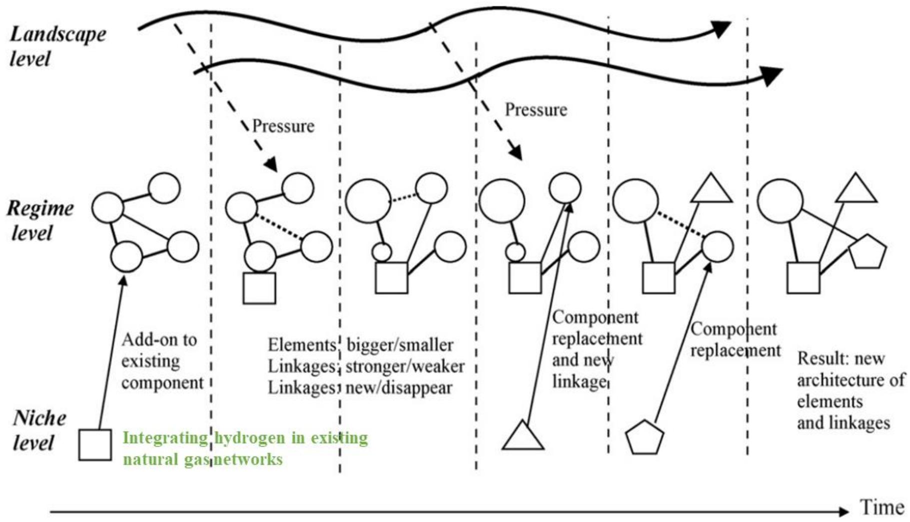

Figure 7. Reconfiguration Pathway (adapted from Geels & Schot, 2007)

Innovation pathways can change over time which is visible within the RED (Geels et al., 2016; Verbong & Geels, 2010). Firstly, this process can be seen as a transformation pathway but involves a de- and re-alignment pathway because due to RED III, the existing fossil-based hydrogen supply will encounter profitability problems and will probably collapse in the long term (Geels et al., 2016).

Both governmental strategies envision mainly the transformation pathway, a pathway also desired by the industry as complete substitution is impossible. The moderate landscape pressure 'European Green Deal' gradually adjusted the orientation of incumbent actors but the green hydrogen niche still has difficulties in emerging to the regime as the market has to be developed. MLP can aid in designing effective policies where continuous monitoring and revision are essential. Transition pathways are complex and overlapping instead of linear and distinct. The research demonstrated that different elements from different pathways can coexist and improve the understanding of how transitions unfold in practice. The dynamic impact of landscape pressures highlights the importance of external pressures in accelerating or hindering niche development. Transition pathways and supportive measures must prioritise social equity and environmental benefits.

5.2 Impact Green Hydrogen Regime

The common usage of hydrogen in the industry is as feedstock but hydrogen also has the potential to reduce the reliance on fossil fuels within the industrial context (Kazi et al., 2021). Since the use of hydrogen is different in both regimes, it is plausible that the green hydrogen niche will impact the regimes differently.

The transition to green hydrogen must be economically viable and equitable. A fair distribution of job creation and economic growth across different regions and social groups has to be ensured. Green hydrogen reduces CO_2 emissions, however, the production process can have an environmental impact including water consumption and land use possibly impacting ecosystems and biodiversity. Energy security can be enhanced with green hydrogen by diversification of the energy mix. However, the intermittency of renewable energy delivers an unstable green hydrogen supply and possibly an increased reliance on fuel-based backup systems or search for alternatives such as nuclear energy. It is essential to consider complementary solutions like heat pumps, CCS etc. as these can ensure energy efficiency, a transitional solution and a resilient energy supply.

A complete substitution for green hydrogen as raw material is impossible due to the high cost and the infrastructure needed. A transition phase of blue hydrogen is required to develop the green hydrogen market, but RED III blocks this by obligating a share of RFNBO hydrogen and blending fuels with renewable molecules. ETS can be considered an instrument aiming to transform grey hydrogen into green hydrogen. However, with a 100% emission reduction target, the LCOH would increase dramatically, indicating the need for a transformation pathway (Mingolla et al, 2024). It can be remarked the fertiliser industry and the energy companies have a lot of power. The fertiliser company can choose to import green ammonia from other countries, slowing down the development of the green hydrogen market locally. The fossil fuel companies have a big responsibility regarding CO_2 emissions (IEA, 2023). If they do not have an incentive to invest in hydrogen, the hydrogen economy and the energy transition can be delayed. Hydrogen can be used to remove sulfur from crude oil so it would be remarkable if green hydrogen is used to decarbonise the sulfur removal operation and to increase the production with the corresponding increase in flue gas and CO_2 emissions (Speight, 2016). At least the use of green hydrogen for this operation is already a CO_2 emission reduction. Green hydrogen should replace the current fossil-based hydrogen in the manufacturing regime. Although a steady baseload is desired for the manufacturing industry, it is difficult to achieve due to the intermittency of wind and solar energy during hydrogen production (Barigozzi et al., 2024). Blue hydrogen is pointed out as a transition technology and is arguably closer to regime integration compared to green hydrogen as the blue hydrogen niche requires the least change (Raven et al., 2016). Some interviewees proposed nuclear power for hydrogen production to supply the manufacturing industry in both countries which is not mentioned in the governmental strategies. The fact that the Dutch interviewees proposed nuclear energy is remarkable since the share of nuclear power is only 4% in the Netherlands (Rijksoverheid, n.d.).

Within the energy regime in industry, there is less enthusiasm for the use of hydrogen. Achieving high temperatures or fulfilling the heat demand with electricity is difficult and hydrogen could be an option to substitute fossil gasses and decarbonise the industry (Samsatli & Samsatli, 2019). Alternative technologies such as heat pumps or burning natural gas with CCS are preferred (Pimm et al., 2023). In the horticulture sector, the single purpose of hydrogen would be heating and hydrogen will always be considered to store an oversupply of renewable energy instead of battery storage. This indicates an addition to the energy mix to generate flexibility. Belgium prefers using electricity and sets low targets for green hydrogen production while the Netherlands seem to have a more accepted status for green hydrogen due to grid congestion issues.

Regarding both regimes, there is a difference in impact of the green hydrogen niche according to the interviewees. Green hydrogen is desired to be the main share of the hydrogen mix which indicates an evolution towards a stretch-and-transform empowerment of the green hydrogen niche since control policies will phase out fossil fuels and quotas (RED III) will force actors to invest in this type of hydrogen (Smith & Raven, 2012). Within this regime, the refineries and the fertiliser industry seem to be highly influential regarding the emergence of the green hydrogen niche. On the other hand, green hydrogen will only have a limited share of the current energy mix. Therefore, this indicates a fit-and-conform form of empowerment for the green hydrogen niche where green hydrogen has to compete on many levels. For heating purposes, it has to compete with natural gas with CCS or heat pumps and for electricity storage, it competes with e.g., batteries (Pimm et al., 2023; Pellow et al., 2015).

5.3 Limitations

In this study, the most important industrial sectors regarding hydrogen uptake were represented by only one interviewee giving only one perspective in their sector and limiting the generalisability. Also, no environmental organisations, citizens, or research institutes were interviewed. More interviewees lead to more robust perceptions as interviewees may be influenced by the company's vision. The governmental strategies are predictions of a desired future consisting of lots of assumptions. The SNE framework is applied to future outlooks and there are many uncertainties about the future of green hydrogen. Recurrent revision of the policies and the dynamics occurring with respect to green hydrogen can confirm or contest earlier findings as a snapshot comparison can not capture all dynamics. The hydrogen strategy has been set as a boundary and further regulations were neglected besides the RED III since this legal framework has a significant influence in the context of green hydrogen.

Chapter 6 Conclusion and Future Outlook

In this research, a comparison is made between Belgian and Dutch hydrogen strategies and industrial stakeholders' perspectives by the use of transition pathways within the MLP and the SNE framework. Transition pathways are complex and overlapping instead of distinct and linear. The research demonstrates different elements from different pathways can coexist and improves the understanding of how transitions unfold in practice. The significant and dynamic impact of landscape pressures highlights the importance of external pressures in accelerating or hindering niche development. The Belgian and Dutch governments mainly envision a transformation pathway where moderate landscape pressures occur when the green hydrogen niche is underdeveloped. This pressure leads to a gradual adjustment of the direction of the green hydrogen development path and reorients the innovative activities of incumbent actors. This pathway is also desired by the industrial stakeholders as complete substitution is considered impossible.

Regime integration of the green hydrogen niche within the industry has a different impact on the manufacturing and energy regimes. In the manufacturing regime, green hydrogen is preferred to be the main share of feedstock. Fertiliser and refinery companies could largely influence the emergence of the green hydrogen economy. Within the energy regime, green hydrogen only tends to be a part of the energy mix according to the stakeholders of both countries. The transition to green hydrogen provides energy security by diversification of the energy mix but it has to be economically viable and equitable. Besides the CO_2 emission reduction, green hydrogen production has an environmental impact with potential harm towards ecosystems and biodiversity. The intermittency of green hydrogen production and unstable supply sustains the reliance on fossil-based systems. Green hydrogen should be complemented with other solutions e.g., heat pumps, CCS and renewable energy to ensure energy efficiency, a transitional solution and a resilient energy supply.

Industrial stakeholders in Belgium and the Netherlands generally align their visions with governmental strategies through a shared recognition of the importance of financial instruments, regulatory frameworks and the formation of networks and market development. However, several challenges and divergencies could be detected. The SNE framework aided in identifying the shortcomings of effective protection of the green hydrogen niche. The main outcomes from industrial stakeholders on both strategies were firstly inadequate shielding by budget misallocations and low funding despite existing shielding initiatives. This is even the case for the Netherlands which can rely on a larger budget. Secondly, the key aspects of nurturing were present in both strategies, however, remarks were made by stakeholders to further improve nurturing. Thirdly, RED III tends to have a disempowering effect. Altogether, the industrial stakeholders of both countries want an integral approach to obtain effective protection of the green hydrogen niche and facilitate regime integration. Effective and well-designed policies are needed that balance the SNE aspects and should be continuously monitored and revised.

Broadly, the strategies of Belgium and the Netherlands showed similarities. A difference was the higher potential of green hydrogen production, more agreements (less in-depth), more financial resources and a more developed and accepted status regarding green hydrogen in the Netherlands. This provides the Netherlands less international dependency and a diversified energy mix. Belgium prefers to use electricity and sets low targets for green hydrogen production. Lower financial resources make Belgium dependent on European instruments. It is useful to investigate the hydrogen strategies of other countries since different challenges may come across and give a broader understanding of the socio-technical transition of hydrogen in the industry. Also, the scope can be extended from industry to transportation, storage technology, etc. to capture broader dynamics and obtain a complete analysis of the green hydrogen context and could even be compared to other sustainable solutions and technologies. Both strategies can influence societal issues such as technological innovation, energy security, environmental sustainability and social equity. Differences in approach can highlight the impact of national capabilities, sociocultural context and broader political frameworks regarding the development and integration of green hydrogen technologies. Due to cohesion existing between Member States, cross-border collaboration can enhance the hydrogen economy in multiple countries. Regarding different federal structures, it is possible to investigate in future work the specific institutional and political factors shaping the hydrogen strategies as well as EU policies reshaping national strategies. Early adoption generates a competitive advantage in the global markets and attracts international attention and investors. Effective niche protection facilitates regime integration and has to be achieved by collaborating and sharing mutual beliefs. A successful implementation of green hydrogen into the industrial regimes will aid in achieving a carbon-neutral society and ensure a sustainable future. Effective strategies often involve partnerships and this collaboration can amplify resilience when crises occur.

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Appendix

Semi-Structured Interview Questions

These are the interview questions posed to industrial stakeholders and policy advisors. A distinction of additional questions is made between hydrogen producers and policy advisors. Questions asked to all will be marked by '*ALL'*. All questions have an explanation about the achievement of the question.

Industrial Stakeholders

1) **The Hydrogen Economy and the idea of green hydrogen use have existed for a long time but didn't take off in the past. According to you, will it take off now? What is the difference between now and the past? *(ALL)***

   Aim: to find the reasons behind the failure of green hydrogen adoption and what the differences are now in adopting green hydrogen in the industry

2) **Looking ahead, what are your expectations for the role of green hydrogen as a sustainable solution for meeting the energy and feedstock needs of industries (in Belgium/the Netherlands) in the next decades? Will fossil-based hydrogen still have a share or will the whole system be changed?**

   Aim: insights about the industrial regimes. Also, the question about if the system will change will give information about the empowerment of the protective space.

3) **What are the largest barriers to the adoption of green hydrogen in the industry? *(ALL)***

   Aim: to find the barriers to green hydrogen adoption

4) **Do you know the hydrogen strategy of the Netherlands/Belgium?**

   Aim: Knowledge about the hydrogen strategy is important before the next question

5) **Can you share your perspective on the hydrogen strategy made by the government supporting the development and utilisation of green hydrogen in the industry? Is there enough emphasis on Green Hydrogen? And what additional measures do you think could be effective?**

   Aim: to find the perspectives of industrial stakeholders on the hydrogen strategy, seeking missing and ongoing SNE aspects and identify transition pathway elements

6) **Do you feel enough support or incentives from the government regarding green hydrogen projects? Why, and how? Or why not?**

   Aim: looking for shielding and nurturing aspects

7) **How do you perceive the level of collaboration and knowledge-sharing among industry peers and stakeholders regarding green hydrogen?**

   Aim: looking for nurturing aspects

Additional Questions for Hydrogen Producers

8) How do you anticipate the scalability and availability of green hydrogen production to meet the demand of industrial applications in the near future?

Aim: insights regarding the manufacturing and energy regimes

9) What are the key considerations and challenges associated with sourcing renewable energy for green hydrogen production, and how do you foresee these evolving in the coming years?

Aim: looking for nurturing and empowerment aspects for green hydrogen production

Additional Questions for Policy Advisors

10) Can you elaborate on any measures taken by the government to support the uptake of green hydrogen in order to relieve potential market barriers or resistance from industrial stakeholders (fossil-based hydrogen)? Are there any regulatory frameworks or financial mechanisms in place for green hydrogen initiatives to counteract the competition?

Aim: Answers to this question will have a linkage to shielding, empowerment & nurturing

11) What is the priority, green hydrogen as a feedstock or for industrial processes and what would be the impact? Do you think it will be an additional option or will it cause a shift and remove other options?

Aim: to find the impact of green hydrogen regarding manufacturing and energy regimes

12) What steps are taken to empower underrepresented groups, stakeholders or regions to actively participate in and benefit from the green hydrogen transition?

Aim: to find nurturing aspects regarding social hydrogen networks

13) Are there any conflicts between industry and governmental strategies? Are there different perceptions/solutions? From your perspective, what are the key factors driving or inhibiting alignment between stakeholders' visions and governmental strategies regarding green hydrogen adoption in current industrial practices?

Aim: This question investigates the alignment between government and industrial stakeholders and the collaboration in decision-making. Looking for nurturing aspects

14) What are the biggest differences and similarities between the Dutch and the Belgian hydrogen strategy?

Aim: Find perspectives on other countries' hydrogen strategy