MASTER THESIS

Barriers to the Implementation of Water Electrolyzers for green hydrogen production in the Netherlands

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Abstract

Climate change, scarcity of resources, waste generation, and deforestation are all worldwide issues caused by the overuse of unsustainable fossil fuels. By raising people's knowledge of the issue, there is a new consensus that a transition to a new clean and sustainable energy system is required. In this sense, the hydrogen economy is gaining traction, with the fundamental idea being to use renewable energies to create hydrogen from water using electrolysis processes employing water electrolyzers. This technology is regarded as one of the most promising for contributing to the desired sustainable energy system. It is not, however, an easy transition, nor is it merely a technological transition. Energy systems, as socio-technical systems, are typically locked in various processes, are path dependent, and several modifications on multiple dimensions are required for a transition to occur.

To that end, and to understand what impedes or fosters this transition, this study investigates the barriers to the implementation of water electrolysis for green hydrogen production in the Netherlands by analyzing the interaction of dynamics at three levels of socio-technical regime, niches, and the landscape. To achieve this, a study of the implementation of water electrolysis for green hydrogen production in the Netherlands was conducted, which was based on semi-structured interviews with 11 experts and desk study of relevant literature.

It was found in this study that water electrolyzers are having difficulty breaking out of their niche and breaking into the mainstream regime. They are still in their infancy and confront multiple difficulties. Although global and European landscape developments in energy supply security and climate change, as well as Dutch climate movements put the pressure on the current grey hydrogen production regime and open up a window of opportunity for sustainable production methods of hydrogen and specifically green hydrogen production in the Netherland, there are barriers on both regime and niche level that impede the transition. The regime is locked- in on multiple dimension and there are barriers on policy, market and user preferences, and technology trajectories. The niche also suffers from a lack of precise expectation articulation and a poorly organized network of actors with problems in learning processes.

Key Words: Socio-Technical Systems, Transition, Multi Level Perspective, Hydrogen, Water Electrolysis, Water Electrolyzers, Barriers, Strategic Niche Management, Protective Space, MLP, SNM.

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List of Abbreviations

AE	Alkaline Electrolyzer
AEM	Anion Exchange Membrane
ATR	Autothermal Reforming
CCS	Carbon Capture and Storage
EU	European Union
FCH JU	Fuel Cell and Hydrogen Joint Undertaking
FME	the trade association for the technological-industrial sector
GHG	Green House Gas
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
MLP	Multi-Level Perspective
NECP	National Energy and Climate Plan
OPEC	Organization of the Petroleum Exporting Countries
PEM	Polymer Electrolyte Membrane
RVO	Netherlands Enterprise Agency
SMR	Steam Methane Reforming
SNM	Strategic Niche Management
SOE	Solid Oxide Electrolyzer
UNFCC	United Nations Framework Convention on Climate Change

Chapter 1 : Introduction

This chapter is divided into 5 sections. It begins with a discussion on why it is necessary to study the barriers to the implementation of water electrolyzers in the Netherlands. Following that, the research gap will be addressed in the section 2. The study objective will be defined in Section 3 of this chapter, followed by research questions in Section 4, and the chapter will conclude with a thesis outline in section 5.

1.1 The need to study the barriers to the implementation of water electrolyzers

The Dutch government, in accordance with its international commitments intends to introduce green hydrogen as an energy carrier by 2030. The goal is for green and import hydrogen to be sufficiently commercial, allowing the hydrogen chain to spread further and, eventually, phase out blue hydrogen (CE Delft, 2018). It also urges that the European emission reduction goal be further tightened to 55% by 2030 – an intermediate target on the road to an expected 80-95 per cent reduction by 2050 (CE Delft, 2018). This implies that some other climate-neutral energy carriers, such as liquid fuels and renewable gaseous, will have to meet 40-60 per cent of the future energy demand (Detz et al., 2019). In this respect, hydrogen is seen as an important alternative fuel resource and energy carrier in the future decarbonized energy system.

However, generating enough sustainable hydrogen to serve as an energy carrier in the envisioned decarbonized energy system remains a challenge. Although hydrogen is the most commonly found element on the globe and may be found in a range of materials as a component of diverse compounds, finding pure hydrogen in nature is a difficulty (Detz et al., 2019).It is not the only problem , however. Another remaining challenge is that Of all hydrogen produced currently up to 96% of hydrogen is obtained from fossil fuels (Burg, 2020). These ways of producing hydrogen are not viable, and the need to produce hydrogen from renewable energy and more sustainable sources must be explored further (Ursua et al., 2012). This is true in the Netherlands as well. Industry in the Netherlands produces roughly 800,000 tons of hydrogen each year for its own production operations (TNO, 2020). To shift the unsustainable methods of hydrogen production, alongside with introducing carbon capture storage (CCS) technologies with non-renewable methods of production of hydrogen such as Methane steam reforming, oil/naphtha reforming (Shiva Kumar & Himabindu, 2019), another way to achieve this target is by switching to the electrical production of hydrogen using water electrolyzer technologies (TNO, 2020).

Water electrolyzers can produce environmentally safe and high purity hydrogen (99.999 percent) in manufacturing process that uses water to generate pure hydrogen and oxygen (Shiva Kumar & Himabindu, 2019). Water electrolysis hydrogen production systems powered by renewable energies are gaining popularity because they are thought to be the only way to produce large quantities of sustainable hydrogen without emitting pollutant gases or using fossil or nuclear resources (Ursua et al., 2012). Because of the ease with which the process can be integrated with renewable energy sources, it is widely considered as the most promising future method of sustainable hydrogen production (Ursua et al., 2012).

Transitioning to a renewable hydrogen energy system by producing green hydrogen through water electrolysis, on the other hand, is a difficult task. It is not a transition from one technological system to another, but rather a transition from one socio-technical system to the other. Cultural and symbolic meanings, technology, infrastructure, policy, market and user preferences, maintenance networks, and production systems are all related in this view, rather than the artifacts themselves. The basic idea is that in order to understand the barriers to the implementation of water electrolyzer it is necessary to have a broader point of view and analyze this implementation in the context it is used.

1.2 Lack of study related to the hydrogen production

As an energy carrier, hydrogen ,as discussed earlier, has the potential to play a critical role in decarbonizing the energy system and mitigating climate change (Ursua et al., 2012). However, most transition literature focuses on the use of hydrogen rather than its production, for example, on hydrogen cars; there is little emphasis on the methods and technologies for producing hydrogen for use in various applications. In this section, I first elaborate on prominent approaches to provide the reader with an overview of current transition studies analytical frameworks, primarily Multi-Level Perspective (MLP) and Strategic Niche Management (SNM), as well as their limitations to assess hydrogen production technologies transition.

In sustainability transitions , policy, economics, technology and culture, are all intertwined (Verbong & Geels, 2010). This needs the development of analytical frameworks to evaluate and comprehend such changes across multiple dimensions. To investigate such developments, these analytical frameworks are addressed in the sustainability transition research stream. Several frameworks have been proposed to analyze transition and system innovation. There are some relevant framework on macro theories such as technological discontinuity and long wave theory on techno- economic paradigm shifts (Twomey & Gaziulusoy, 2014) and also theories that are more focused on organizations, such as the disruptive innovation theory. These frameworks, however, have many similarities with the innovation systems approach and the socio-technical transitions approach (Twomey & Gaziulusoy, 2014) . There are four founding frameworks in the field of sustainability transition studies: the Technological Innovation System approach (TIS), The Multi-Level Perspective (MLP), Strategic Niche Management (SNM), and Transition Management (TM) (Köhler et al., 2019). They are all methodical in their approach to understanding co-evolutionary complexity and basic phenomena such as emergence, path-dependency, and non-linear dynamics. (Köhler et al., 2019) and lock-in (Unruh, 2000) .

The Multi-Level Perspective and Strategic Niche Management frameworks have been previously used in the literature in studies related barriers to the implementation of sustainable technologies. Berkeley et al., (2017) used The Multi-Level Perspective (MLP) framework to analyze European battery electric vehicle (BEV) adoption and automobile transition. Bößner et al., (2019) used MLP to analyze the Barriers and opportunities to bioenergy transitions in Indonesia. And recently

Bakhuis, (2019) and Bakhuis,(2020) use the combination of MLP and SNM to evaluate the barriers to the introduction of respectively solar energy on Caribbean Small Island Developing States and hydrogen transition in the Netherlands. Moreover, a study that specifically deals with the barriers of the implementation of water electrolyzers, as the niche, in the Netherlands was not observed in the literature. The focus of this research, however, is on the transition of green hydrogen as an energy carrier using water electrolyzers in the Netherlands. To achieve this, since there are two niches of green and blue hydrogen competing at the same niche to gain resources and support to break through the incumbent regime of grey hydrogen, it appears to be necessary to make a comparative analysis for these two niches regarding their internal niche processes to research the zero-carbon hydrogen transition and the sustainable production technologies used in these processes.

1.3 Research Objective

Water-electrolyzers are thought to be a significant part of the future energy transition, particularly in the Netherlands. However, because these technologies are still in their early phases of development, they will need to undergo various modifications, not only in terms of technological advancements, but also in the social context in which water electrolyzes operate. A study that considers several facets of this socio-technical transformation is required to understand if this transition is achievable and what potential hurdles may exist. To that end, the primary goal of this research project is to explore the barriers to the implementation of water electrolyzers in the Netherlands by evaluating the dynamics of three interconnected layers of landscape, regime, and niches that water electrolyzers are a part of.

1.4 Research Questions

The preceding section explained why it is necessary to investigate the barriers to water electrolysis implementation in the Netherlands, as well as the scarcity of research in the literature. This section will discuss the research questions that will guide the remainder of the study.

Research Question	"What are the barriers in the development of green hydrogen production technology with the focus on water electrolyzers in the Netherlands?"

Sub Research Question:

Three Sub Questions support the research main question. These sub-research questions will serve as the foundation for the investigation of dynamics at various levels of regime, niche, and landscape that will be required to answer the main research question. The following are the sub-questions:

SRQ 1	What are the landscape dynamics to open up windows of opportunities for more sustainable hydrogen production technologies?
SRQ 2	What are regime dynamics in terms of technological, political, and other lock-ins or path dependencies?
SRQ3	How do the blue hydrogen niche and the green hydrogen niche compare and contrast in terms of expectations, learning processes and network-building?

1.5 Thesis Outline

This thesis includes 5 chapters. The first chapter described the research and stated why it is important to investigate the barriers to the adoption of water-electrolyzers. The background and theory will be covered in the second chapter. The methodology will be explained in Chapter 3, and it will serve as the framework for the analysis in Chapter 4. In Chapter 4, I provide an understanding of probable barriers at work by evaluating and addressing dynamics at three levels of landscape, regime, and niche. This will be accomplished using theoretical frameworks, MLP, and Strategic Niche Management concepts. Finally, the chapter 4 analysis will lead to a conclusion that will be explored in chapter 5.

Chapter 2: Background & Theory

This chapter is divided into three sections. First, an overview of two significant niches of blue and green hydrogen, as well as what these two niches signify and how they differ technically. The many techniques of hydrogen generation will be presented, which will aid in gaining a better knowledge of the green hydrogen and blue hydrogen niches, which are major concepts in this thesis. Second, the historical backdrop for the emergence of the hydrogen economy will be offered to review the developments that led to the emergence of the hydrogen economy. Finally, the theoretical foundation and key concepts such as landscape, niche, regime will be explored. In doing so, the following analytical frameworks are required: Multi Level Perspective (MLP) and Strategic Niche Management (SNM).

2.1 Hydrogen Production methods and hydrogen economy background

The word hydrogen appears to have a straightforward definition. However, complexities arise, particularly in the categorizations and different names used to represent various manufacturing methods. The literature sometimes categorizes hydrogen production methods based on the source of energy used to produce it. Figure 1 depicts a high-level overview of hydrogen classification.

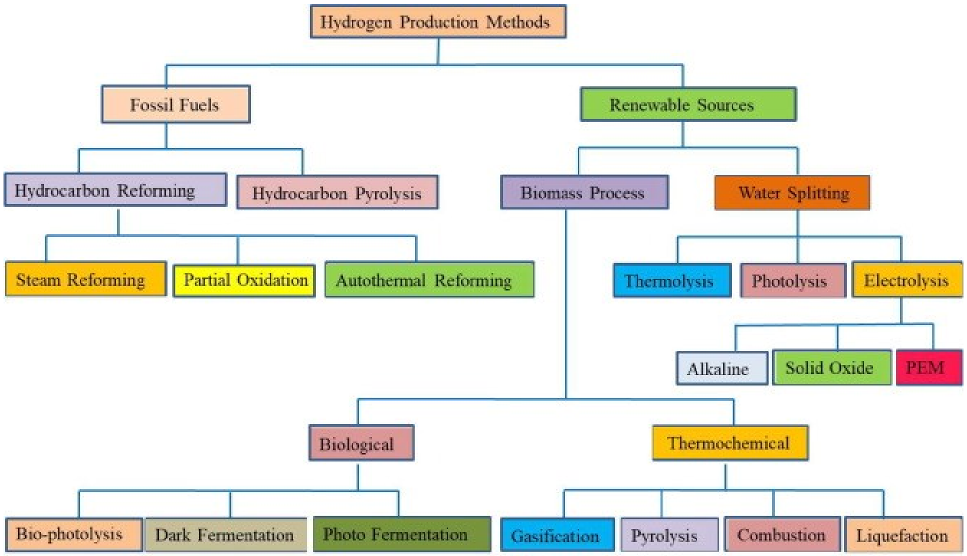

Figure 1: Hydrogen production Methods. Adapted from (Shiva Kumar & Himabindu, 2019)

Another classification divides hydrogen into gray, blue, and green based on the raw materials and production path. Gray hydrogen is produced during the refining of fossil fuels. When carbon emissions are collected, stored, or used, hydrogen is referred to as blue. Green hydrogen is hydrogen produced using renewable energy sources. Wind, solar, nuclear, hydropower, geothermal, and biomass are all renewable energies that can be used to generate green hydrogen (Atilhan et al., 2021).

2.1.1 Hydrogen Production in the Netherlands

To clarify the differences between gray hydrogen production methods and water electrolysis as emerging sustainable green hydrogen production technologies for further investigation, Weeda and Segers (2020) provided an overview of hydrogen production processes in the Netherlands by distinguishing hydrogen as the main product or as the product released. This section relies heavily on this reference.

2.1.2 Grey Production Methods of Hydrogen

Steam reforming

The procedure can be carried out in a variety of ways. The two main procedures are steam methane reforming (SMR) and autothermal reforming process (ATR) (Weeda & Segers, 2020). SMR is a process of extracting hydrogen from natural gas, with natural gas as the primary fuel source (Weeda & Segers, 2020). Steam reforming hydrocarbon gases produces the vast majority of hydrogen produced in the Netherlands (Weeda & Segers, 2020). ATR generates heat by burning a portion of the hydrocarbon feedstock within the reactor (Weeda & Segers, 2020). If hydrogen is needed, it must be produced using pure oxygen, which necessitates the use of an air separation system in ATR hydrogen production (Weeda & Segers, 2020).

Gasification

The process of converting solids to gas is known as gasification. Coal, biomass, waste, and heavy residues from oil refineries can all be used as feedstock (Weeda & Segers, 2020). Only heavy oil refining residues are currently used in gasification processes in the Netherlands, such as ExxonMobil's Flexicoker process and Shell's Gasification Hydrogen Plant (Weeda & Segers, 2020).

Catalytic reforming

The catalytic reforming process converts heavy naphtha into liquid 'Reformate,' which is used as a blending ingredient in high-octane gasoline (Weeda & Segers, 2020). As a byproduct of this process, hydrogen gas is produced. Catalytic reforming is a critical step in the oil refining process (Weeda & Segers, 2020).

Steam cracking or naphtha cracking

In the petrochemical phase of steam cracking, saturated hydrocarbons are broken down into smaller, mostly unsaturated hydrocarbons (Weeda & Segers, 2020). Dow Chemical , Sabic, and Shell Chemicals all run massive steam cracking plants in the Netherlands (Weeda & Segers, 2020) .

Coke's production

Cokes are brittle, hard fuels with a high carbon content that are mass-produced at TATA Steel in Ijmuiden (Weeda & Segers, 2020). It is used as a fuel and a reducing agent in the smelting of iron ore in blast furnaces (Weeda & Segers, 2020). The product is made from low-ash and low-sulfur bituminous coal that has been heated in the absence of air to temperatures ranging from 1000 to 1100 degrees Celsius (oxygen) (Weeda & Segers, 2020).

2.1.3 Green Production methods of Hydrogen

There are several electrolysis technologies to choose from. I will only introduce technologies that can be scaled up in the Netherlands within the next five to ten years for the purposes of this study. This is particularly true for two emerging market technologies: the Alkaline Electrolyzer (AE) and the Proton Exchange Membrane (PEM) (Stevelink & Pukala, 2020). Other technologies, such as the Solid Oxide Electrolyzer (SOE) and the Anion Exchange Membrane (AEM) Electrolyzer, are still in the research and development stage (Stevelink & Pukala, 2020).

Alkaline Electrolyzers

Alkaline electrolysis is the most advanced electrolyzer technology, with many large-scale plants in operation for decades (Suurs et al., 2020). Alkaline electrolyzers are suitable for high-pressure applications because they operate at ambient or elevated pressures and use little or no precious/expensive materials in their construction (Suurs et al., 2020). They do, however, have a lack of dynamic response and have large footprints (Suurs et al., 2020). These issues must be addressed before renewable energy technologies can be integrated for the purpose of producing green hydrogen (Suurs et al., 2020).

PEM Electrolyzers

Electrolyzers with proton exchange membranes (PEMs) have been around since the 1960s, when General Electric first used them in NASA's space program and have mostly been used for small-scale applications (Suurs et al., 2020). PEM technology has gained traction in the last decade, with many multi-MW installations currently under construction (Suurs et al., 2020). These are the lightest and most dynamic electrolyzers, and they produce hydrogen under pressure, making it ideal for storage and handling (Suurs et al., 2020).

2.2 Historical context: the emergence of Water Electrolysis Technology and current Hydrogen Economy

This section focuses on the history and background of water electrolysis technology, as well as the emergence of hydrogen economy. This section is important to understand how these two fundamental notions of the current study came to be and why they are relevant as a research topic.

2.2.1 Background of hydrogen as an energy carrier and water electrolysis technology

Using hydrogen as an energy carrier and its production using water electrolysis processes are not new ideas or concepts. Hydrogen as an element has been known since the early sixteenth century, when Swiss physician Paracelsus discovered it (Dawood et al., 2020). in 1761 ,for the first time, Robert Boyle used diluted acids and iron filings in order to produce hydrogen (Dawood et al., 2020). Until the 1960s, some countries used hydrogen in the form of city gas for street lighting and domestic energy supplies (cooking, heating, and lighting) (Wietschel, 2006). And it was in the 1970s, during the oil crisis, that the concept of a hydrogen-based energy system developed (Wietschel, 2006). Hydrogen has also been used as a chemical feedstock in processes like ammonia synthesis and hydrogenation of crude oil (Wietschel, 2006). In the late 1990s, advances in fuel-cell technology renewed interest in hydrogen (Wietschel, 2006).

Water electrolyzers are also not a new technology: alkaline electrolysis was used to produce hydrogen for commercial fertilizers from the 1920s to the 1960s before being replaced by natural gas-derived hydrogen (Zoulias & Varkaraki, 2004). Water electrolysis has a lengthy history, dating back to the first industrial revolution in 1800, when Nicholson and Carlisle were among the first to discover that hydrogen may be created electrically by decomposing water (Zoulias & Varkaraki, 2004). There were even more water electrolyzers by 1902 (Zoulias & Varkaraki, 2004), and Sir William Robert Grove in 1839 invented the first hydrogen-powered fuel cell (Dawood et al., 2020) . In 1948, the first massive water electrolysis plant went into operation. (Zoulias & Varkaraki, 2004). In 1948, Zdansky and Flonza created the first pressurized industrial electrolyzer (Zoulias & Varkaraki, 2004). In 1966, General Electric invented the first solid polymer electrolyte device

(SPE), and in 1972, it invented the first solid oxide water electrolysis unit (Zoulias & Varkaraki, 2004).The first modern alkaline systems were introduced in 1978 (Zoulias & Varkaraki, 2004).

2.2.2 History of energy supply and emergence of hydrogen-based economy

Since the mid-nineteenth century, energy carriers have steadily transformed from solid gaseous to liquid (Wietschel, 2006). Until the middle of the nineteenth century, the primary energy source used by humans was biomass (wood). Around the year 1700, as the demand for energy in England increased due to population growth, wood began to be substituted by coal. (Wietschel, 2006). Around the turn of the century, in addition to coal as an energy source, oil began to emerge in developing countries and the United States (Wietschel, 2006). The widespread use of oil then coincided with the expansion of the vehicle industry and the introduction of the combustion engine in 1885 (Wietschel, 2006). Natural gas is currently displacing oil as a home heating fuel and other fuels as a source of electricity generation (Wietschel, 2006).

Hydrogen's usage as an energy carrier predates its use as a chemical substance (Wietschel, 2006). Its industrial manufacturing began in 1920, with BASF's first commercial scale ammonia synthesis in 1913 as an example (Wietschel, 2006). Since the 1950s, hydrogen has been used to power fuel cells in space exploration (Wietschel, 2006). The concept of a “Solar Hydrogen Energy Economy” emerged in the 1960s, with several scientists claiming that it is feasible to use renewable solar energy to separate water into hydrogen and oxygen (Wietschel, 2006). Fuel cells and hydrogen are currently the subject of numerous national and international research and collaboration activities, as well as numerous pilot projects, particularly in the EU, the United States, and Japan (Wietschel, 2006).This significant advances in fuel cell technology in the late 1990s, combined with growing concerns about the security of supply of fossil energy sources and climate movements have centered attention on hydrogen in recent years in the energy policy debate, primarily as a sustainable energy career to phase out unsustainable fossil fuels (Wietschel, 2006).

2.3 Theoretical Background

The purpose of this study is to identify the barriers to the implementation of water electrolyzers. To achieve so, theoretical frameworks capable of identifying the dynamic of change on multiple levels should be used. In other words, if we want to study the barriers to water electrolyzer implementation, we need theories to help us understand what defines a successful transition, what is missing, and what is enforcing the transition of water electrolyzers. To answer these concerns, literature review reveals that a sustainability transition research that tries to address comparable issues aligns with the goal of this research (Köhler et al., 2019).

According to the literature on sustainability transitions, in order for sustainable technologies to be generally embraced, a fundamental shift in current production and consumption systems is required (Köhler et al., 2019). As a result, researchers in this discipline have been working to answer the question of how sustainable technologies evolve and how they might help with system change (Raven et al., 2016) . Geels, 2002 speaks of technological transition as "major technological transformations in the way societal functions such as transportation, communication, housing, feeding, are fulfilled.". He believes that" technological transitions do not only involve changes in technology, but also changes in user practices, regulation, industrial networks, infrastructure, and symbolic meaning or culture."

By the end of the 1990s, Strategic Niche Management (SNM) (Kemp et al., 1998; Weber et al., 1999) was developed to serve as a tool for policy making and research framework to manage technological innovations in the niche level (Loorbach & van Raak, 2006). Multi-level perspective on the other hand is based on a multi-level conceptualization of socio-technical regimes, which is in interaction with a slowly changing landscape and emerging niches (Loorbach & van Raak, 2006). Both of these analytical methodologies have been used in a variety of transition studies as complementary frameworks.

To analyze the dynamics and understand the barriers in this study, the Multi-Level Perspective approach and Strategic Niche Management frameworks are used to analyze the current situation of green hydrogen production in the Netherlands and the existing barriers to up-scaling in order to answer the previously stated main research question. First, in this section of theoretical background, Multi-Level Perspective will be reviewed to understand crucial terms such as Landscape, Regime, and Niches. Following that, the notion of Strategic Niche Management is elaborated, and ultimately, the typology of assessing expectations on many levels will be presented. This allows the research question about obstacles to the implementation of water electrolysis technologies be addressed.

2.3.1 Multi Level Perspective

In transition studies, the Multi-Level Perspective is a popular approach (MLP). This approach incorporates institutional theory ,evolutionary economics, and innovation sociology, (Geels, 2020) . It is argued that transitions occur as a result of dynamic processes occurring within and between three analytical levels which according to Köhler et al. (2019) are: " 1) niches, protected spaces and the focal point for radical innovations; 2) socio-technical regimes, represent the institutional structuring of existing systems, leading to path dependence and incremental change; 3) external socio-technical landscape developments." (Köhler et al., 2019). A nested hierarchy or multi-level view can be used to describe the relationship between the three notions (figure 2).

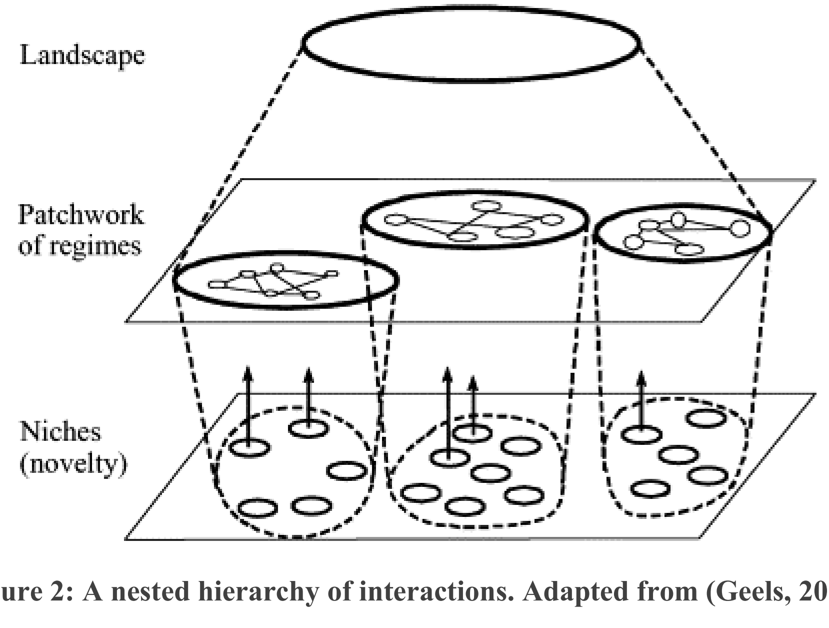

Figure 2: A nested hierarchy of interactions. Adapted from (Geels, 2002).

The multi-level perspective underlines that successful implementation of a technological niche is influenced not only by internal processes in the niche, but also by developments in the socio-technical regime and landscape (Geels, 2011b). In other words, this is the alignment of developments in these three interconnected levels that determines whether or not a regime shift occurs. For the niche innovation to be widely diffused the destabilization of the regime is a key factor. The regime can be destabilized either when Landscape developments put pressure on the incumbent regime toward desirable changes or it might be the result of internal tensions in regime that might result in fractures and cracks in the regime and opening up a window of opportunity for the niche technology to break through (Geels, 2011). This idea is presented in figure 3.

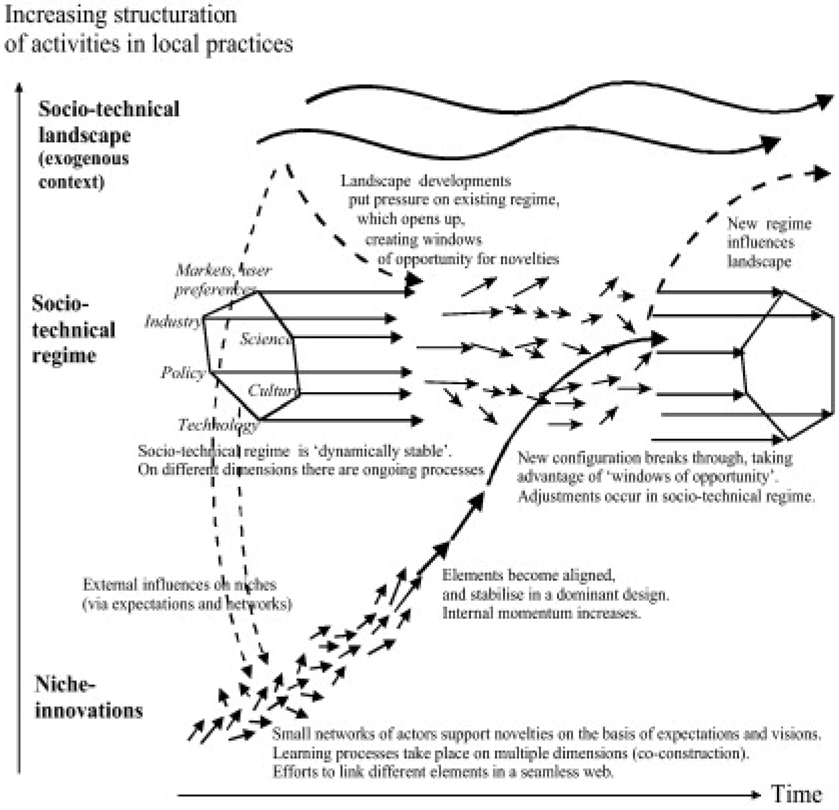

Figure 3: A dynamic multi-level perspective on system innovations. Adapted from (Geels, 2011)

Landscape

The socio-technical landscape refers to characteristics of the exogenous environment developments that influence sociotechnical development (Geels, 2005). Oil prices, economic growth, conflicts, emigration, broad political alliances, cultural and moral values, and environmental challenges are all examples of landscape developments (Geels, 2002). Actors do not have direct control over such developments at this level, and these developments cannot be facilitated or slowed down at the whim of actors or social groups (Geels, 2005).

Regime

In a multi-level perspective, the socio-technical regime is the level that guides and coordinates the activity of key social groups to stabilize the current systems (Geels, 2005). Geels, (2002) expands on Rip and Kemp's (Rip & Kemp, 1988) definition of a “technological regime” : a system of rules or principles that is integrated in engineering practices, and introduces the concept of a “socio-technical regime” (Geels, 2002). He emphasizes in his definition that the rules and practices that constitute a regime are not only shared by engineers and scientist but also shared by all types of businesspeople, end users, leaders, societal interest groups, organizations, and so on (Geels, 2002).

However, the regime concept has been criticized in the literature when it comes to empirical studies (Markard & Truffer, 2008). First, there is no explicit distinction between actors, institutions, and technological artifacts (Markard & Truffer, 2008). Another difficulty in empirically defining is that the terms "socio-technical regimes" and "socio-technical systems" are not used consistently in the literature on technological transitions (Markard & Truffer, 2008).They point out the inconsistency in Geels publications using the terms socio-technical systems and socio-technical regimes.

For the purpose of this study and make a clear distinction between these inconsistencies, I build on the definition of socio-technical regime by (Geels, 2004). Explaining that in order to understand the dynamics of socio-technical systems it is important to take into account the co-evolution of multiple trajectories, he distinguishes five important trajectories at the regime level : policy, regulation, market user preferences, culture, science, and technology (Geels, 2004) . It is the coordination and co-evolution of these dimensions that stabilizes the regime. However, in the literature, tension in internal dynamics of these dimension has been introduced as another source of destabilization of the regime and opportunity for the niches to diffuse. If the internal dynamics of each of these dimensions or among each other linkages are week, it can be noticed as a driver for the transition. On the contrary, when the internal dynamics are strong, they pose a barrier to the transition. Therefore, in regime analysis in search for drivers and barriers to the transition of water electrolyzes I consider the dynamics and probable strength or weaknesses between these dimensions an apply my analysis base on this distinction. This distinction is shown in figure 4 as follows.

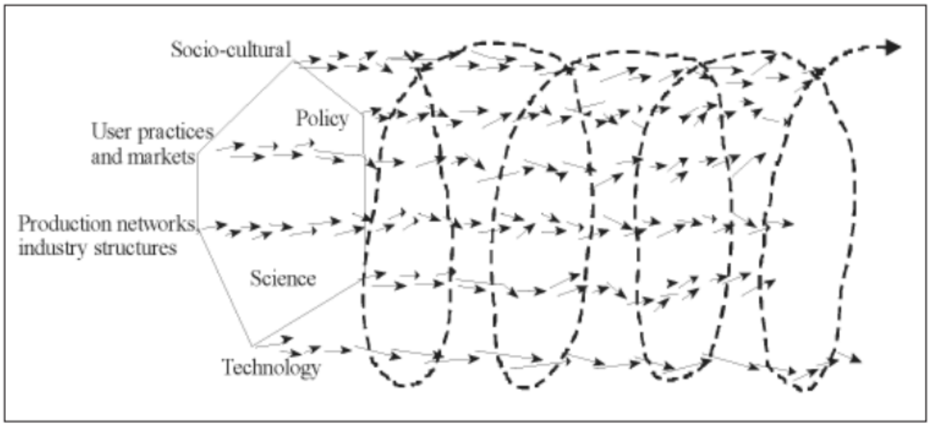

Figure 4: Alignment of trajectories in different regimes. Adapted from *(Geels, 2004)*

Niche

While regimes are known for incremental innovation and stability of current socio-technical systems, niches are known as protected space for radical innovation (Geels, 2002). There are some characteristics that make niches especial in the view of transition. First, niche technologies are costly, with low technical performance this necessitate specific protection for them to be sheltered from regime regular selection environments and provide a space for nurturing and empowerment (Geels, 2002, Smith & Raven, 2012). Second, Niches are important to learn and build network necessary for the support necessary for successful diffusion (Geels, 2002).

Based on the prior discussion, three distinct levels of niche, regime, and landscape are delineated for the purposes of this study, as illustrated in figure 5.

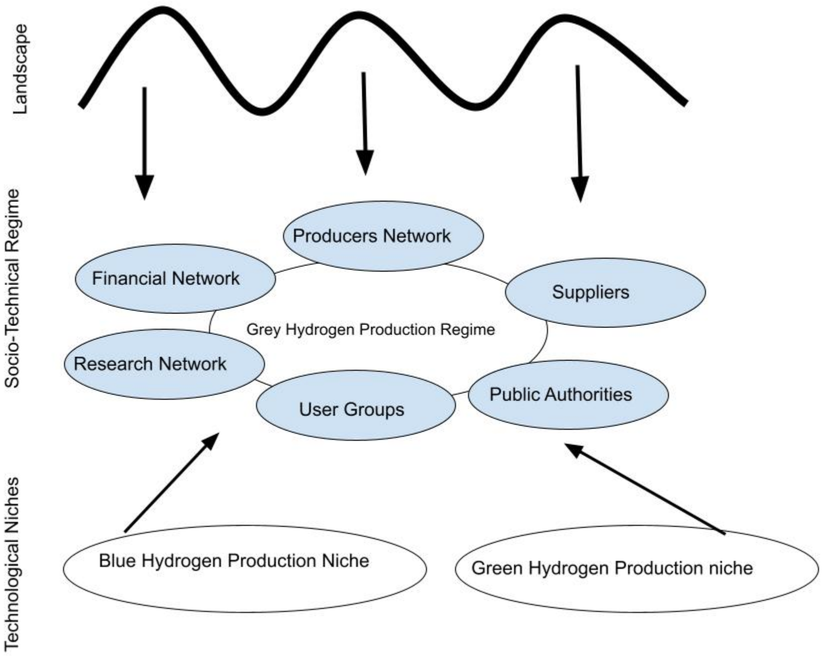

Figure 5: Overview of delineation of the Regime and Niche

2.3.2 Strategic Niche Management

This section describes Strategic Niche Management (SNM) framework. This framework can be utilized to analyze the micro-level dynamics of the green and blue hydrogen production niches. This analysis is required to comprehend the impediments to the application of water electrolysis technology in the Netherlands.

Technological innovation, according to the SNM approach, can be aided by the creation of protected spaces known as technical niches (Geels, 2002). It is in these protected spaces that co-evolution of regulatory institutions, user behavior, and technology can be experimented (Schot & Geels, 2008). Role of niche-internal processes such as learning, networking, and articulation of expectations have been the focus of the research using SNM approach (Schot & Geels, 2008). However, these focus on internal process has been corrected later by considering external processes on the regime and landscape level to these internal processes (Schot & Geels, 2008). In this aspect, the multi-level approach was useful for contextualizing SNM.

The theory behind early SNM research is that incumbent technologies can be replaced if new technologies are exposed to the market using niche development processes (Schot & Geels, 2008) . This replacement would result in emergence of a new socio technical regime with its own set producing, regulating and usage rules (Schot & Geels, 2008). Three (internal) processes were identified and proposed for effective development of a technical niche by Schot and Geels (2008):

1. Expectation and visions articulation
2. Social networks building
3. Multi-dimensional Learning processes

Expectations (Schot & Geels, 2008)

1. Expectations would help to develop a successful niche if they are

- shared by broad actors
- explicit
- of higher quality: meaning that the substance of expectations is validated by ongoing projects.

Social Network Building (Schot & Geels, 2008)

2. Social networks are more effective in stimulating niche growth if:

- The networks are broad, including various types of stakeholders to facilitate the articulation of different viewpoints.
- The networks are deep: Organization representatives should be able to attract support and resources needed for transition.

Learning Process (Schot & Geels, 2008)

3. Learning processes that are not first order, only focused at data and facts, but also second order that enable changes in assumptions and mental frames. Schot and Geels (2008) propose this learning should happen in multiple dimensions of 1) technical aspects 2) market and user preferences 3) cultural and symbolic meaning 4) infrastructure and maintenance network 5) industry and production networks 6) regulations and government policy 7) societal and environmental effects.
   In this study then in order to analyze the learning processes I base my analysis on these seven mentioned dimensions.

2.3.3 Expectation analysis in this Study

Strategic Niche Management literature argues that for a niche to be successfully implemented there should be alignment in the expectation of actors in niche and regime levels (Schot & Geels, 2008). An unanswered question in the literature is however: " how to understand if the expectations are aligned in niche and actor regimes" (Yang et al., 2020). To answer this question Yang et al., (2020) proposed a "typology of alignment patterns between niche and regime actors' expectations" . Based on SNM literature they proposed two dimensions to measure expectations alignment between niche and regime actors : 1) Breadth of alignment : refers to how widely and how broadly expectation is shared, the more shared it is, the more likely the expectations to turn to shared goals, 2) Depth of alignment : the same concept as the " quality and specificity" of shared expectations in strategic niche management literature (Yang et al., 2020).

In hydrogen sustainable niches there are two niches that are at the same time competing and have complementary effects on each other. In order to measure the expectations in these two niches in a more systematic way this typology is used in this study in expectation analysis (section 4.3.2.1). This typology then is further explained.

Yang et al (2020), suggest three steps to take in order to take different types of alignment into consideration. These steps are as follows.

Step 1: identification of expectations at three different levels of landscape, regime and niches (Yang et al., 2020)**.**

Landscape Level Expectation:

Refers to actors' expectations of the external environment's development, for example: climate change or environmental challenges.

Regime Level Expectations:

Refers to how actors perceive the regime durability in answer to both internal tensions and external forces. In case actors expect the regime to be destabilized and are doubtful about stability of the regime it might result in niche growth.

Niche Level Expectations:

Refers to how actors expect the future performance of specific niche. In case the perceived expectation is ambitious it might result in niche acceleration.

Step 2: measuring breadth of alignment between niche and regime actors at each separate level (Yang et al., 2020)**.**

For the transition to take place the priorities of niche and regime actors at each level should match and be coordinated (Yang et al., 2020). Yang et al. (2020) typology helps to analyze this level of alignment coordination for each of the three levels separately. They defined three types of alignment between niche and regime actors:

“ (1) *sparse alignment*, no regime actors align with niche actors;

(2) *broad alignment*, all of the regime actors align with niche actors.

(3) *selective alignment*, where some regime actors align with niche actors, an intermediate state between sparse and broad alignment.”

Step 3 : Building Alignment Patterns (Yang et al., 2020)

By combination of step 1 and step 2 the alignment we can then conclude the degree of alignment of expectations in specific niches (Yang et al., 2020). Based on the proposed typology Strong alignment refers to alignment types VIII, IX, XI and XII, which have broad alignment at landscape level and at least selective alignment of expectations at both niche and regime level (Yang et al., 2020). In this situation niche acceleration is highly probable (Yang et al., 2020). Medium-strong alignment refers to types IV, VI, VII, X and Weak alignment refers to types I–III, V (Yang et al., 2020). This alignment pattern is shown in figure 5.

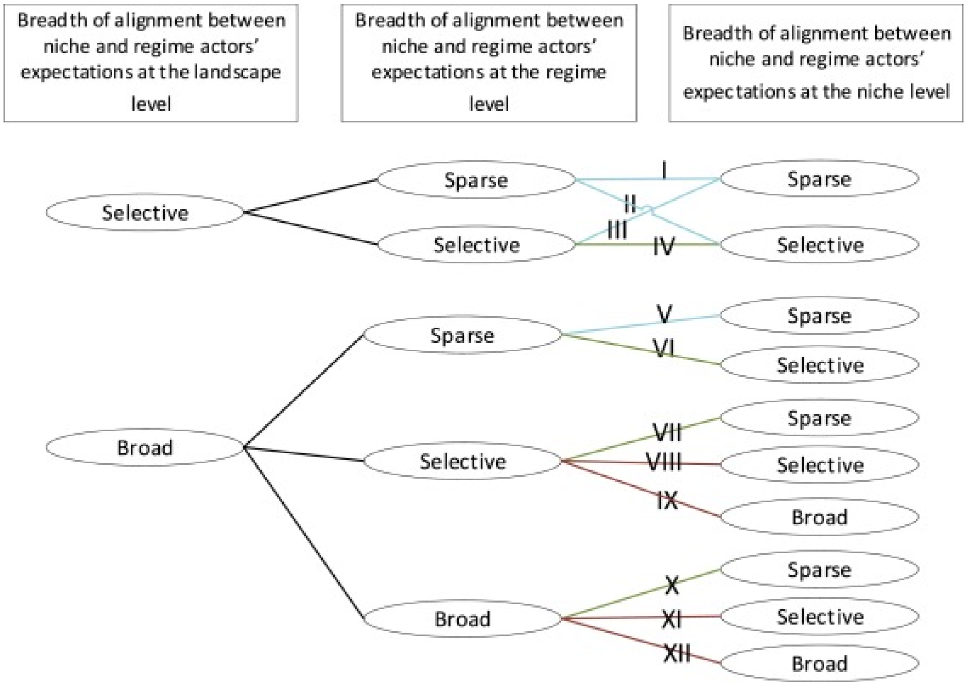

Figure 6: Alignment patterns between niche and regime actors' expectations. Adapted from *(Yang et al., 2020)*

Chapter 3: Methodology

This chapter describes the methodology and framework that were utilized to answer the main research question stated in section 1.4. To that end, this chapter is organized into three sections. Section 1 depicts the research design, which includes the research framework, strategy, unit, boundaries, materials, and methods of access. Section two covers data analysis methods, an analytical framework, and data validation. This chapter concludes with an ethical statement.

3.1 Research Design

3.1.1 Research Framework

To provide the framework required to address the main question, I rely on seven steps proposed by Verschuren and Doorewaard (2010) . These seven procedures, if taken sequentially, can help to provide the appropriate framework for the study. The following are the steps and their linkages in creating the framework for this study.

Step 1 : Characterizing the objective of the research project:

The main objective of this study is to investigate the implementation barriers of water electrolyzers, used for green hydrogen production, in the Netherlands by analyzing the dynamics in three interlinked levels of niche, regime and landscape.

Step2: Determining the research object.

Research object of this study is the Netherlands in general. Water electrolyzer for green hydrogen production will be the main focus in addition to Dutch government, academic institutions, citizens and businesses and stakeholders.

Step 3: Establishing the nature of research perspective

The research provides insights into the challenges of implementation of water electrolysis for green hydrogen production in the Netherlands. The nature of this research perspective is a practice-oriented conceptual model to examine these barriers.

Step4: Determining the sources of the research perspective:

Scientific literature and previous studies on system innovation, transition theory, Multi-Level Perspective, and Strategic Niche Management will be examined. on top of that, interviews with experts, informants and respondents in green hydrogen production in the Netherlands will be conducted. These sources of research are mentioned in table 1.

Table 1: Sources of Research Perspective

Key Concepts	Theoretical Frameworks
Green Hydrogen Energy Transition Water Electrolyzers	Multi-Level Perspective Strategic Niche Management

Step 5 : Schematic Representation of the framework

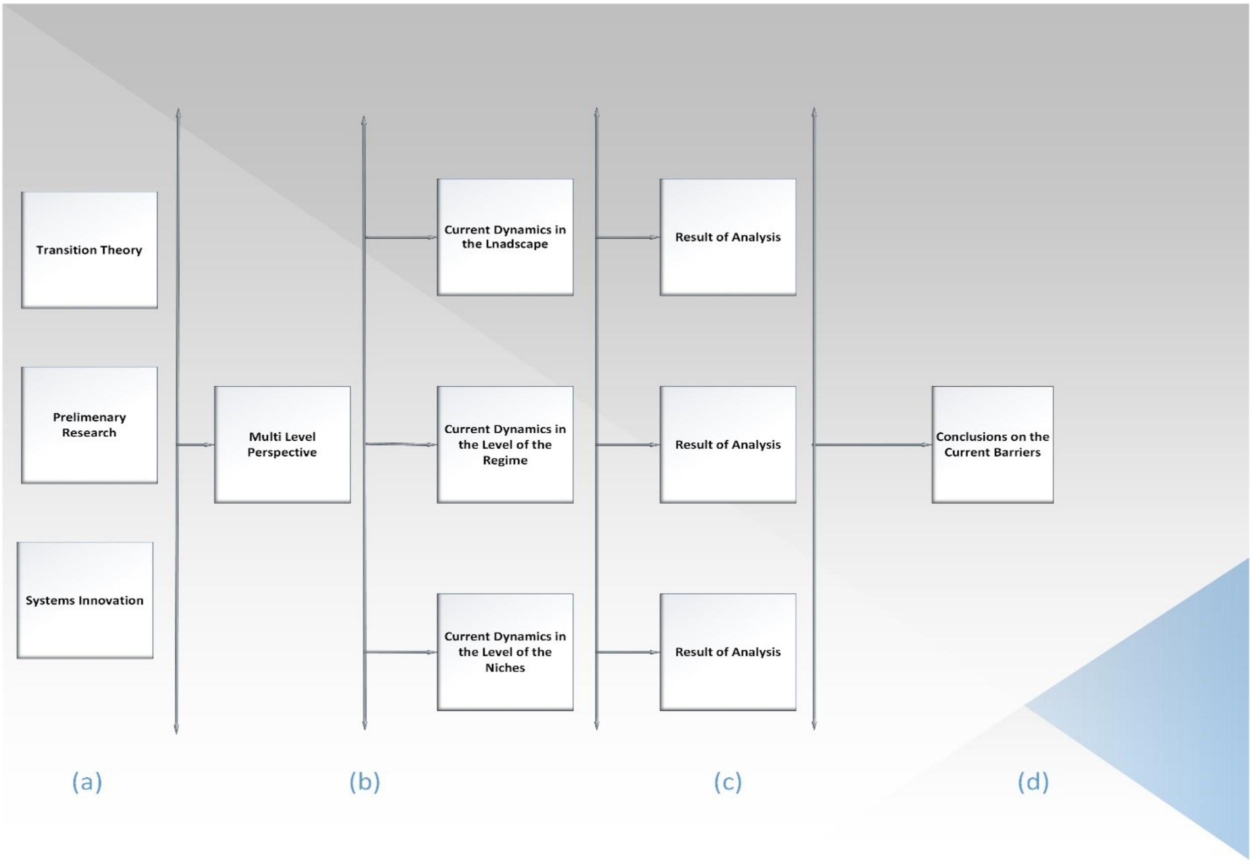

Figure 7: schematic presentation of the framework

Step 6: Formulating the research framework in the form of arguments:

A study of the implementation of water electrolyzers for green hydrogen production in the Netherlands, based on interviews with experts and the review of relevant scientific literature, employing multi-level perspective and strategic niche management analytical frameworks to assess potential obstacles in the landscape, socio-technical regime, and niche. A comparison of the results of these analyses leads to a conclusion on the likely barriers to the deployment of water electrolysis in green hydrogen production in the Netherlands.

Step 7: Checking whether the model requires any change:

At this stage, there is no indication that anything needs to reformed**.**

3.1.2 Research Strategy

The strategy of this research is a qualitative, in depth using combination of methods of desk research and interviews.

3.1.3 Research Unit

The research unit in this study is the Netherlands energy sector, renewable energy sector (those related to green hydrogen economy) and different stakeholders.

3.1.4 Research Boundaries

Regarding the time constraint to conduct the research, this research project only focuses on the obstacles for the implementation of water electrolysis and no other green hydrogen production technologies such as biomass.

3.1.5 Research Material and Accessing methods:

According to Verschuren et al., 2010 "Research materials are referred to as the way of identifying and operationalizing the key concepts of the research objective, as well as the research questions." The materials and how to get access to them are covered in this section.

The primary sources for this research would be journal reviews, secondary literature (books, manuals, etc.), and gray literature (PhD and master thesis and etc.). People are also important as a source from which to obtain and inquire information. Respondents, informants, and green hydrogen experts comprise the people source. Table 2 shows the data and information needed to address the sub questions:

Table 2: Research Material and Accessing methods

Sub Research Questions	Required data/Information	Source of data	Accessing the data
What are the landscape dynamics to open up windows of opportunities for more sustainable hydrogen production technologies?	Key Landscape factors, political, economic, environmental.	Secondary Data: journal reviews, secondary literature (books, manuals, etc.), and gray literature	Content analysis
What are regime dynamics in terms of technological, political, and other lock-ins or path dependencies?	Alignment and weaknesses in the regime level dynamics that pose barriers to the implementations or possible tensions that offer drivers.	Secondary Data: journal reviews, secondary literature (books, manuals, etc.), and gray literature Primary Data: Respondents, informants, and green hydrogen experts	Content analysis Questioning: Online Interview
How do the blue hydrogen niche and the green hydrogen niche compare and contrast in terms of expectations, learning processes and network-building?	Dynamics and interactions in internal niche processes, learning, expectations, network building.	Secondary Data: journal reviews, secondary literature (books, manuals, etc.), and gray literature Primary Data: Respondents, informants, and green hydrogen experts	Content analysis Questioning: Online Interview

3.2 Data Analysis

3.2.1 Analytical Framework

Data analysis as one of the important steps of research is defined as the method of analyzing data using a logical and empirical sense. The objective of data analysis is to obtain relevant and reliable information. A mixture of primary and secondary data will be used to address the study sub questions. The primary data gathered from interviews will be analyzed using constant comparison methods. In coding analysis, a deductive approach will be used, and the analysis may be subjected to inductive analysis in an iterative method.

STEP 1 : To respond to the first sub-question, To comprehend and evaluate the current green hydrogen external interaction context, also known as the socio-technical landscape, it is appropriate to have awareness of environmental issues, resource scarcity, cultural and normative values, and broad political coalition. In this regard, secondary data on green hydrogen policy agendas, and studies, as well as different political coalition viewpoints on green hydrogen, environmental issues, and environmental movements and NGOs, are relevant. The requisite data will be subjected to content analysis. This step will answer the first sub-question.

STEP 2 : Explaining the ongoing dynamics in the coexisting socio-technical regime of hydrogen production necessitates awareness of various technological, policy, scientific, socio-cultural, and consumer market regimes. Secondary data will be obtained by content analysis of policy documents, journals, newspapers, media, documents, and archival records that are available. In addition, primary data will be obtained through interviews with informants, experts, and respondents in the field of hydrogen production. The obtained data will be analyzed using constant comparison method and classical content analysis. This step will answer second sub-question.

STEP 3: At the niche level, in order to evaluate the success or failure of this transition process, data on three internal niche processes, namely articulation of expectations, social networks, and the learning process in the niche of water electrolysis for green hydrogen production, should be collected. This knowledge requires interviews with water electrolysis experts and informants. Furthermore, secondary data on these processes will be gathered through the use of papers, journals, theses, and books. This step will address the third sub-question, resulting in an answer to the main research question.

3.2.2 Validation of data analysis

The data triangulation technique would be used to ensure the accuracy and validity of the data and information collected, as well as to remove any possible bias. The use of multiple data and information sources is needed for data triangulation (Guion, 2002). Desk research and interviews will be the primary sources of knowledge and data in this report. The results of the desk research will be compared with the results of the interviews to validate the data. If the findings of desk research and interviews about particular problems and issues match, this can be regarded as evidence of the validity of the data and information analysis.

3.3 Ethics Statement

The ethical considerations related to data collection and the prevention of violation to interviewees are pursued in this study, as outlined in the University of Twente's Research Ethics Policy (Balogh, 2020)

- Protect the confidentiality of research participants
- Any data or information gathering for the study can only take place with the consent of the interviewee.
- In the investigation, any deceit or falsification of data or information will be avoided.
- Maintain participant and organization anonymity.
- Ascertain that data and information from interviewees are properly classified.
- In the interview, offensive or discriminatory questions will be avoided.

Chapter 4 : Results and Discussion

The findings from interviews and the literature are presented in this chapter, together with a discussion of dynamics based on the findings at three distinct levels of landscape, regime, and niche. These analyses present the results for three sub-research questions that are required to answer the main research question. This chapter is divided into three sections. Each chapter will present the results and findings, followed by a discussion and conclusion. Section one discusses the findings and dynamics at the landscape level. The dynamic of the grey hydrogen regime on policy, market users and preferences, price will be presented and analyzed in section two. The chapter concludes with a comparative analysis of two green and blue hydrogen niches in order to determine whether these two niches are likely to compete or complement one another. This will be followed by a discussion on the niche level. The analysis and discussions in this chapter will be utilized to base the concluding discussion in chapter 5 and answer the main research question.

4.1 Landscape Level

As an EU member country, the Netherlands' energy transition landscape is influenced not only by national developments, but also by the European landscape and international movements. This necessitates studying multiple landscape scales in order to understand how these three landscapes interact and how they might push or even pull for the transition to a hydrogen-based economy employing water electrolyzers. To achieve this the research was conducted in these three different landscapes. First results for each landscape are presented and then a discussion on the dynamic will be presented in the conclusion part of this chapter.

4.1.1 International Landscape Level

Looking at the Landscape developments in the international level, two challenges have been recognized that have fueled the development of the hydrogen economy: energy supply security and climate change. Energy supply security is a driver that pushes countries toward a more independent supply of energy and reduce their reliance on fossil fuels and especially oil. The reason for this is that world's reserves of oil and natural gas are limited to just a few countries and their resources are also limited. Another significant development on the international landscape is the unsustainable development of energy systems, which endangers the environment and human well-being. As a result, countries are attempting to diversify their energy source, with the shift to hydrogen-based systems serving as a solution (Wietschel, 2006). These landscape developments are elaborated as follows.

4.1.1.1 Energy Supply Security Developments

In terms of significant landscape development on a global scale, many incidents, including the 1970s war, the Iran revolution and Iraq war in 1979, the Kuwait invasion in 1990, the Asian economic crisis in 1998, and the OPEC decision to restrict output in 2000, can be considered events that threatened energy security supply in Western countries and the Netherlands (Wietschel, 2006) . The 1970 oil crisis could serve as a starting point. Three distinct developments in the Middle East sparked the 1970s oil crisis: the Yom Kippur War in 1973 and the Iranian Revolution in 1979, followed by Iran and Iraq war (Wietschel, 2006). Both events caused disruptions in the region's oil supply, posing problems for countries that depend on energy exports from the region (Wietschel, 2006). However, as opposed to other western European countries, the Netherlands' oil supply seemed to be in good condition (Chandler et al., 1999).

The first oil crisis, which occurred in 1973–74, triggered an increase in scientific interest in hydrogen as an energy source and prompted a concerted search for alternative energy sources (Wietschel, 2006). In 1970, General Motors coined the phrase "hydrogen economy" to describe the future fuel supply in the transportation field. The first international hydrogen conference took place in 1974 in Miami, and it has been held every two years since 1976 (Wietschel, 2006). At the same time, the International Energy Agency developed the Hydrogen Implementing Agreement (Wietschel, 2006).

4.1.1.2 Climate Change Developments

The United Nations Framework Convention on Climate Change, the Kyoto Protocol, and the Paris Climate Agreement are three significant climate change landscape developments that have influenced the Dutch hydrogen economy (UNFCCC, 2019a) . Countries signed the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 “as a framework for international cooperation to tackle climate change by limiting average global temperature rises and the subsequent climate change” (UNFCCC, 2019a) .Countries began negotiating in 1995 to improve the response to the climate change on a global level, and two years later, the Kyoto Protocol was adopted (UNFCCC, 2019a). Established country Parties to the Kyoto Protocol are legally required to meet emission reduction goals. The first commitment cycle of the Protocol began in 2008 and ended in 2012. The second commitment period started on January 1, 2013, and ended in 2020 (UNFCCC, 2019a).

On December 11, 1997, the Kyoto Protocol was signed (UNFCCC, 2019b). It took effect on February 16, 2005, after a lengthy ratification period. The Kyoto Protocol puts the United Nations Framework Convention on Climate Change into action by committing developed and developing countries to limit and minimize greenhouse gas (GHG) emissions in line with agreed-upon individual targets (UNFCCC, 2019b). The Convention only requires certain countries, Netherlands as a developed country as part, to implement mitigation policies and interventions and to report on a regular basis (UNFCCC, 2019b).

The 2015 Paris Agreement, which was adopted on December 12, 2015 in Paris, is the most recent phase in the evolution of the United Nations climate change regime and builds on the work done under the Convention (UNFCCC, 2019a). In the global effort to fight climate change, the Paris Agreement sets a new path (UNFCCC, 2019a).

These three important international landscape developments have provided the conditions for European and national policymakers to take action.

4.1.2 European Landscape Level

The European Union aims to become the world's first climate-neutral bloc by 2050 (Monaca et al., 2020) . Significant investment would be needed from the EU, national governments, and the private sector (Monaca et al., 2020).As part of its commitment to the Paris Agreement, Europe launched the European Green Deal, which has proven to be a critical strategy in the transition to hydrogen (Scarlet, 2019). The European Green Deal is a blueprint for making the EU's economy more competitive by converting climate and environmental issues into opportunities in all policy fields, while also ensuring that the transition is fair and equitable for all (Scarlet, 2019). Energy System Integration and Hydrogen Strategy are two significant EU policies that have a direct effect on the introduction of green hydrogen production as part of the green deal (European Comission, 2020).

The EU's Energy System Integration Strategy will serve as the foundation for the green energy transition (European Comission, 2020). The term "energy system integration" refers to the planning and operation of the whole system (European Comission, 2020). This interconnected and scalable system would be more effective, lowering societal costs (European Comission, 2020).This approach is built on three key pillars: 1) a more ‘circular' energy system 2) a greater direct electrification of end-use sectors 3) Clean fuels, such as renewable hydrogen and sustainable biofuels and biogas, are promoted in sectors where electrification is difficult (European Comission, 2020).

The Energy System Integration Strategy outlines 38 measures that will help to integrate the energy system (European Comission, 2020). These include legislative reform, financial assistance, research and deployment of emerging technology and digital resources, advice to Member States on fiscal initiatives and the phase-out of fossil fuel subsidies, market governance reform and infrastructure planning, and enhanced customer knowledge (European Comission, 2020).

Hydrogen can help decarbonize manufacturing, transportation, power generation, and buildings across Europe in an integrated energy system. Via investments, policy, market development, and research and innovation, the EU Hydrogen Strategy aims to transform this potential into practice (European Comission, 2020). Hydrogen might power industries that aren't appropriate for electrification and provide storage to offset intermittent renewable energy flows, but only with concerted public-private intervention at the EU level can this be accomplished (European Comission, 2020).

To do so The European Commission will 1) support the construction of at least 6 gigawatts of renewable hydrogen electrolyzers in the EU, as well as the development of up to one million tons of renewable hydrogen, between 2020 and 2024 2) Between 2025 and 2030, hydrogen must become an integral part of the EU's integrated energy system, with at least 40 gigawatts of renewable hydrogen electrolyzers and ten million tons of renewable hydrogen generated in the EU. 3) Renewable hydrogen technologies can mature and be widely deployed in all hard-to-decarbonize sectors between 2030 and 2050 (European Comission, 2020).

The Commission intends to continue implementing the Strategy by launching the European Clean Hydrogen Alliance with civil society, national and regional ministers, corporate leaders, and the European Investment Bank (European Commission, 2020). The Alliance will build a larger supply investment pipeline and help to develop the EU clean hydrogen market (European Commission, 2020). The European Clean Hydrogen Alliance's goal is to implement large-scale hydrogen infrastructure by 2030, incorporating green and low-carbon hydrogen supply, demand in industry, mobility, and other markets, as well as hydrogen transmission and distribution (European Commission, 2020). Through the alliance, the EU hopes to reinforce its global leadership in this area, which will aid the EU's commitment to achieve carbon neutrality by 2050 (European Commission, 2020).

4.1.3 National Landscape Level

These global and European landscape developments in energy supply security and climate change, followed by climate movements inside the Netherlands committed national government to intervene at the national policy landscape level. The Climate Act of 28 May 2019 sets these objectives (Rijksoverheid, 2020). Policies and plans to achieve these climate change targets can be found in the National Climate Agreement, the National Energy and Climate Plan (NECP), The Climate Plan, and Dutch hydrogen strategy. Hydrogen's role has emphasized in all these policies.

Dutch government strategy on hydrogen makes it clear that the government embraces the role of hydrogen for the future energy system in the Netherlands. This prominent role is communicated by introducing key instruments that are necessary for this transition in the Dutch national climate policy landscape. These instruments are: 1) legislation and regulation, 2) cost reduction and scaling up of green hydrogen through a) financial support schemes for research, scaling up, and rolling out, b) linking hydrogen to offshore wind energy, and C) blending obligation (Rijksoverheid, 2020) . The government's aim is to emphasize the importance of clean hydrogen development and the unique starting position of the Netherlands by using this national strategy (Rijksoverheid, 2020) . Figure 8 summarizes the developments on the landscape level and their interactions.

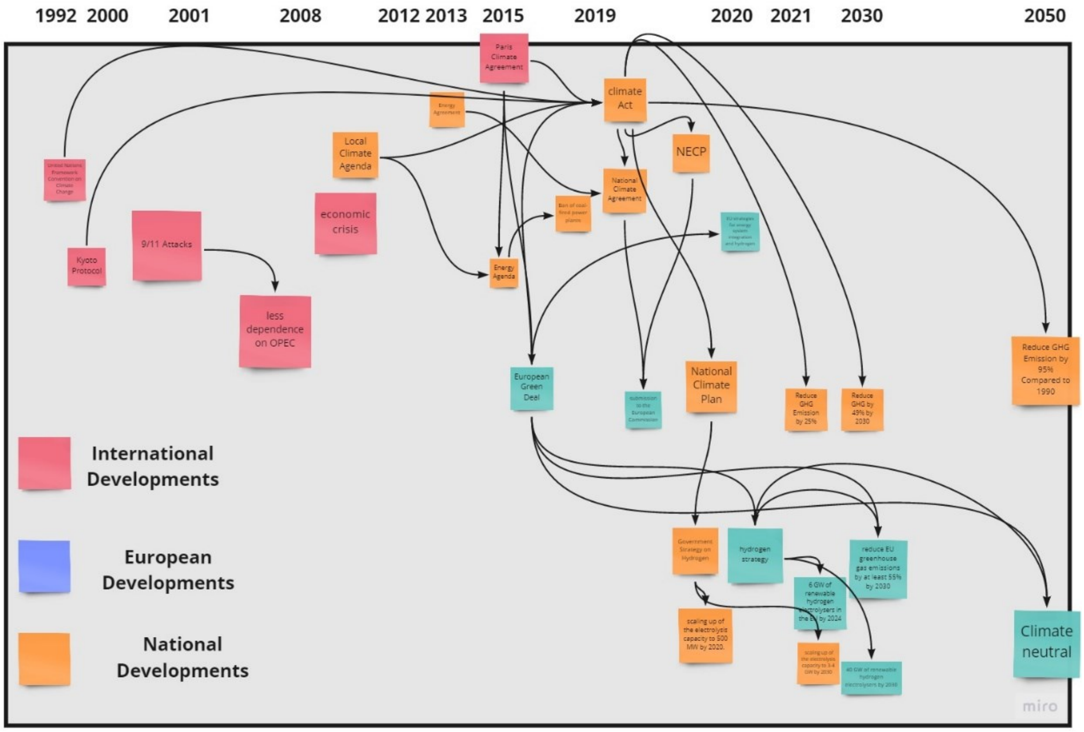

Figure 8: Landscape developments and their interactions

4.1.4 Discussion and Conclusion of Landscape Level Dynamics

In this section, I will highlight the most significant obstacles and drivers in the landscape of green hydrogen production in the Netherlands. Figure 9 depicts three main drivers at the landscape that are pressurizing the regime toward shift for a zero-carbon hydrogen economy. I can then answer the first sub research question of this thesis by evaluating developments at the landscape level based on the findings. The first sub-question is as follows:

First Sub-Question

What are the landscape dynamics to open up windows of opportunities for more sustainable hydrogen production technologies?

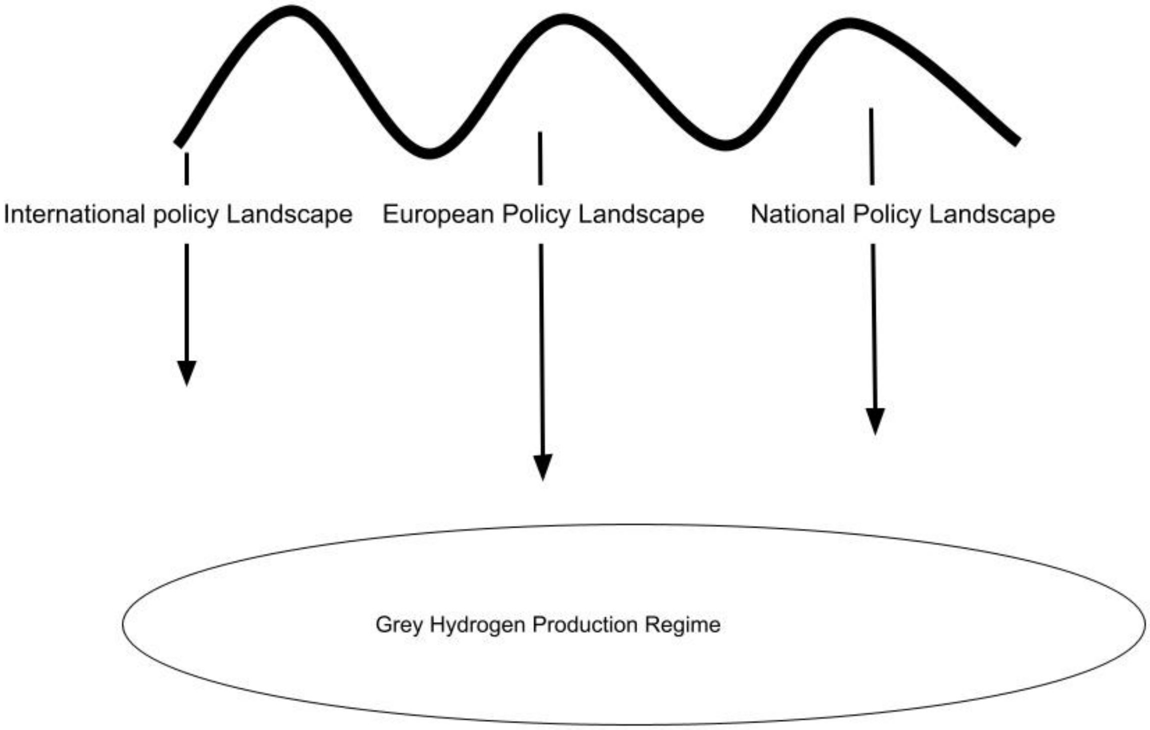

Figure 9: Drivers to the transition in the Landscape level.

At three distinct levels of the global, European, and national landscapes there are developments that put pressure on grey hydrogen production regime to open up and create windows of opportunity for innovations. As previously stated, the majority of these landscape pressures are concerned with climate change, the fuel crisis, and strong political coalitions. According to the international Landscape pressure, two events have fueled the development of the global hydrogen economy: energy supply security and climate change. Several incidents, including the 1970s war, the Iran revolution and Iraq war in 1979, the Kuwait invasion in 1990, the Asian economic crisis in 1998, and OPEC's decision to limit production in 2000, all posed a threat to energy security in Western countries and the Netherlands.

Another significant driver in the landscape is the evolution of the climate movement on a global scale. Three notable climate change landscape developments that have triggered the emergence Dutch hydrogen economy are the United Nations Framework Convention on Climate Change, the Kyoto Protocol, and the Paris Climate Agreement. The European Union is also under pressure from this global landscape movement to consider the transition to renewable hydrogen more effectively. At the European Landscape level, the main goal is to create the world's first climate natural coalition. The green deal strategy has highlighted this trend, as well as the need for a more proactive approach to using renewable energy carriers. The adoption of green hydrogen production as part of the green deal is influenced by two main EU policies: Energy System Integration and Hydrogen Strategy.

Finally, international and European landscape developments in energy supply security and climate change, as well as climate movements in the Netherlands, compelled the Dutch government to intervene and request a shift. This tendency and development in the national landscape may be seen in various recent national agreements and policies introduced by the government. These advancements are putting pressure on the grey hydrogen regime to open up, and a window of opportunity for a transition to a zero-carbon hydrogen energy system is currently open.

4.2 Regime Level

Due to inconsistencies in the definition of socio-technical regime, as previously mentioned in Chapter 2, I built on Geels', (2011) definition of the socio-technical regime, which distinguishes important dimensions at the regime level: policy, regulation, market user preferences, culture, science, and technology. The reason for this distinction has been previously explained in section 2.3.1. Interviewees and the literature focused on the policy, market and user preferences, and technological dimensions of the regime among all of these domains, therefore these three dimensions will be the focus of analysis and discussion in this study. The aim of these analysis is to understand if these dimensions of socio-technical regime align, a sign of stabilization for the regime, or there are tensions and cracks, as a sign for diffusion opportunities. The table depicts various dimensions as well as the barriers that have stabilized the current regime.

Table 3: Barriers on different Regime Dimensions

Regime dimension	Barrier Factor
Policy	Inadequate fiscal incentive
	Uncertainty in Policy
	Inadequate regulation for hydrogen as energy carrier
	Lack of Certification schemes for hydrogen as an energy carrier
Market and User preferences	Price
Technology	Manufacturing Capacity

4.2.1 Policy Dimension

4.2.1.1 Fiscal Incentives

In the National Climate Agreement (Climate Agreement, 2019), the government indicated a strong interest in green hydrogen, with the goal of increasing electrolyzers capacity to around 500 MW by 2025 and 3-4 GW by 2030. It also established various subsidies for industrial research, experimentation, and development, including the Demonstration Energy and Climate Innovation subsidy (DEI+), SDE +, SDE++, and Topsector Energy subsidies (Gigler & Marcel, 2018). A closer examination of the proposed subsidies, however, reveals that, while these subsidies can lead to a reduction in carbon dioxide emissions, one of the most significant challenges is that funding that only encourages investment is no longer sufficient (Gigler & Marcel, 2018).

Two of the interviewees criticized the approach of the government related to hydrogen fiscal incentives stating that “although the Netherlands was one of the pioneers to publish hydrogen strategy, but there is no fund that is connected to those ambitions” (Interviewee #7). Another interviewee stated that “One of the challenges is that the Netherlands is not very keen of having any sort of industry policy. “We embrace the thought of hydrogen, but at the same time, we struggle a little bit with where we want to apply it” (interviewee #8).

The SDE++ scheme, which focuses on large-scale deployment of renewable energy supply as well as other CO2-reducing technologies, is widely regarded as the primary financial support scheme in the Netherlands for the implementation of hydrogen technologies. However, there is still debate about the SDE++ subsidies, and whether Blue Hydrogen production and electrolyzers will receive adequate funding. Many of the respondents in the interviews questioned the Netherlands' fiscal incentives to encourage the adoption of both blue and green hydrogen. The main concern in these interviews was that the existing funding structure, which is thought to encourage the adoption of blue and green hydrogen production, is insufficient.

According to interviewees, SDE will not function for hydrogen applications (Interviewee #8) and does not meet the goal. The fundamental reason for this is that SDE ++ is the only OPEX subsidy in the Netherlands, and green and even blue hydrogen cannot compete with direct electrification (interviewee #7). According to interviewee #8, while SDE++ may support blue hydrogen in the context of CCS, it is ineffective if the goal is to establish a blue hydrogen plant and the necessary transition to blue hydrogen. For green hydrogen, the situation is aggravated because the SDE plan is mostly focused on CO2 reduction rankings, and the current use of water electrolyzers, while still in its early stages, does not fully mesh with the goal of CO2 reduction (Interviewee #8). The same point of view is expressed by interviewee #9, who states that this funding model based on CO2 reduction does not align with the purpose of water electrolysis technology.

4.2.1.2 Uncertainty

Some of the interviewees criticized this uncertainty specially in the terms of regulations. “So, what I think we need is that the regulations have to be in a certain way, and I think more the policies have to be ensured a way that industry knows what the incentives will be in five years, 10 years' time” (Interviewee #9). Same interviewee suggested a need for an action plan as a solution “We need an action plan to say we are going to bring CO2 taxes to this level, we should have very specific regulations we need and you can choose either to use the taxation or CO2 credit costs, whatever that is, or how are going to do it. But you have to say what your intentions are” (interviewee #9).

The role of incentives and such as SDE++ was mentioned by another interviewee mentioning that in the long run it is not clear how it will help the position of green hydrogen. “SDE++ is more like a short-term financial boost and in the long run, I think there should be a clearer picture of the shadow markets. Say, market ordering, I mean, it's very unclear what position green hydrogen go for, for instance, have in relation to also Blue hydrogen, but also other options” (interviewee 3). This lack of clear instrument from a point of view of one of the active potential producers of green hydrogen has been clearly highlighted. In their point of view for companies it is vitally important to know the return on financial terms and based on the current instruments at place it is quite risky for companies to invest in green hydrogen (interviewee #10).

4.2.1.3 Regulations

Government policy, as well as legislative and regulatory provisions, are important components that facilitate hydrogen usage and development while also addressing and resolving potential bottlenecks and obstacles. Although the Dutch government intends to support sustainable hydrogen production, which will mainly rely on electrolysis with renewable electricity, and some policy changes have been made in the area of hydrogen as an energy carrier, they are restricted and only apply to cars and buses. When it comes to automobiles, the regulation is typically pinned on to one for hybrid vehicles.

There are currently no overarching or structural regulations regarding hydrogen as an energy career. If hydrogen is to be implemented as an energy career such as gas it needs to have its specific laws and regulations. “You have the Dutch gas law, and it deals with natural gas, but there's no hydrogen law just yet, there is some legislation around sort of the commercial industrial transport of hydrogen” (interviewee #7). Not having specific regulations for hydrogen as an energy career will have direct effect on its distribution. “A TSO company that distributes energy, it is for them very good to have an electrolyzer to balance the grid. Current legislation forbids them doing that. So, the legislation is not helping, so we have to adjust legislation to the world we want to move to another very difficult at the moment.” (Interviewee #9). It makes it unclear how hydrogen should be distributed and if so, what are the regulations that apply to the distributors. Therefore, it might discourage main TSO companies and distributors to get involved in the supply chain. According to interviewee 8 there are several changes that need to be done in the regulations in terms of gas codes, tariffs, contracts and the list goes on. The role of safety regulations was highlighted by one of the interviewees “There's no safety regulations yet for hydrogen transport at this scale. it's basically something completely new and not too much has been written down. I'm sure you have things to add there.” (Interviewee #7).

4.2.1.4 Certification

Certification is required to confirm the GHG emissions during the manufacture of clean hydrogen in order for it to become a tradeable commodity. According to *Hydrogen Europe (2021*) Different threshold levels are currently emerging in various pieces of EU law and/or notable certification programs, specifically: 1) Sustainable Finance: Draft Delegated Act of the Taxonomy regulation stipulates 2.256 tCO2eq/tH2 2) Renewable Energy Directive GHG methodology proposed foresees that hydrogen for the transport sector would have to be produced at or below 3,38 tCO2eq/tH2; 3) CertfiHy threshold is 4,37 tCO2eq/tH2 (*Hydrogen Europe ,2021*.)

However, some respondents indicated that the lack of a certification that complies with European legislation is another hurdle to the deployment of water-electrolyzers and hydrogen as an energy source in general in the Netherlands. "Certification of hydrogen is one costly, but the most important thing is, there is only one non-official way of certification of hydrogen, and that is a certified project, but that is not official, and it is not, according to the Renewable Energy Directive too." (Interviewee #9). Another interviewee also shares the same concern about the certification and if it can be matched with European and global standards. Not only should the standards and certification match on the European level but they also should match in the global level. (Interviewee #1)

4.2.2 Market and user preferences Dimension

In terms of market and user preferences, respondents stated that the high cost of water electrolysis constitutes another barrier to widespread implementation of water electrolysis. This claim is also consistent with other studies. Gigler and Marcel (2018) investigated the cost of electrolysis-based hydrogen production and compared it to gray hydrogen. They concluded that it is currently difficult to generate at a lower cost than gray hydrogen, even at very low electricity prices (Gigler & Marcel, 2018). "It is evident that a significant amount of work remains to be done in order to produce low-cost, high-yield systems that will allow electrolysis to compete with hydrogen in large-scale industrial applications" (Gigler & Marcel, 2018). In another study, Stevelink and Pukala, (2020) stated that the cost of green hydrogen is not (yet) comparable to fossil alternatives. They stated that they anticipate cost convergence in 2030. However, they believe that important steps must be addressed in the domains of design, materials, components, and subsystems.

One of the interviewees who is active in hydrogen production of green hydrogen also emphasized the high price and its effects on consumers. They believed that at the end the high price of the hydrogen produced by electrolyzers will play a key role in its preferences by the buyers. At this moment the price of green hydrogen produced by water electrolyzers are quite high and this is mainly related to the high expense of electricity (interviewee #9). It was also corroborated in the interviews that one of the concerns is that because there aren't enough supporting incentives, it's tough to lower the end price to make it appealing to consumers and end users. If it is for the government to introduce the green hydrogen, there should be specific incentive for the buyers to be inclined to buy the green hydrogen (interviewee #9).

4.2.3 Technology Dimension

Water electrolysis technology, although believed to play a key role in future, still needs to be more mature and passes its early stages of technological developments. Upscaling existing technologies to the GW-scale plants needed to accelerate the energy transition will be a daunting task (Suurs et al., 2020). In this regard, Suurs et al. (2020) state that to attain the GW scale, serious barriers must be overcome for all viable technologies.

According to them, In general, stack designs must be adjusted to handle more power (higher current density), increase reliability, and allow larger stack sizes without requiring the use of too many (expensive and/or scarce) materials, all while maintaining system integrity and long-term performance (Suurs et al., 2020). Catalysts, electrodes, porous layers of transport and membranes/separators are key areas for advancement at cellular level (Suurs et al., 2020). Here, a compromise between costs/use of content and performance/durability of the part must be sought (Suurs et al., 2020). Effectiveness of use and recycling potential is especially important for PEM and SOE processes, where there is a significant impediment for upscaling in the lack of such raw materials, such as iridium, platinum and rare earth elements (Suurs et al., 2020). It is vital for the latter, especially in view of large-scale deployment, to establish solutions for recycling and replacement (Suurs et al., 2020).

Another Barrier identified in that study is water electrolyzers are manually assembled now (Suurs et al., 2020). Low-cost, effective and durable stack modules are required for large scale application that are easily integrated into large electrical systems which fulfill upstream and downstream process requirements (Suurs et al., 2020). Such digital production is yet to be conceived. Automated production is a significant potential to reduce costs for both the components (cell level) and the integrated stacks core of the electrolyzer (Stevelink & Pukala, 2020). One of the challenges is that no standard product is actually available (Suurs et al., 2020).It is also noticed that there is a lack of harmonized technology specifications, research protocols and well-defined metrics, due to the existing state of the art in which different projects are designed and installed incrementally (Suurs et al., 2020). This hinders a rational contrast of goods, the reduction in the machine expense and R&D progress in organizations. Markets also demand the proper functioning of laws, codes and norms (Suurs et al., 2020).

4.2.4 Discussion and Conclusion on Regime Level Dynamics

In this section, I will highlight the most significant barriers in the regime of green hydrogen production in the Netherlands. I can then answer the second sub research question of this thesis by evaluating developments at the regime level. The second question is as follows:

> What are regime dynamics in terms of technological, political, and other lock-ins or path dependencies?

The policies of the government could be an important barrier. Despite being committed to environmental conservation and other social goals, the government has not indicated a specific action plan or strategy for new green hydrogen generation technologies and systems. The signals are paradoxical when it comes to blue and green hydrogen. For example, subsidies support virtually all emerging technologies, despite the fact that it is unclear what function they should serve. This is the challenge in the Netherlands for zero-carbon hydrogen production in general, and in particular in terms of water electrolysis subsidies. Due to insufficient fiscal incentives, policy uncertainty, inadequate regulation for hydrogen as an energy carrier, and a lack of certification schemes for hydrogen as an energy carrier, investors and actors in the field of green hydrogen production in the Netherlands have been hesitant. The government's main goal and strategy are equally ambiguous, as are the ways of achieving them. As a result of this ambiguous signal, producers and investors remain unsure about market trends and will be unwilling to invest.

Pricing barriers are also based on the market and the preferences of the users. Limited scale production of water electrolyzers make them an expensive option to be purchased by potential customers. However, this high price is not only the result of lack of mass- production but also it is because they heavily rely on the price of renewable electricity. However, green hydrogen, even if the price of electricity drops, is still more expensive than grey hydrogen to be produced. It is clear that in order to create a system that can compete with gray hydrogen regime there is still several steps to be taken in terms of lowering the cost and making the product marketable.

Another significant impediment to the introduction and use of water electrolysis technology is that it needs technological advancement. Water electrolyzer technology needs to be improved. They are still in the early stages of development. This in turn makes it an expensive option and keeps it in low scale production. It is a loop of optimization, testing by consumers, redesigning. Water electrolyzers must be tested for large scale production and they are still subject to several changes.

According to the preceding facts and debate, various socio-technical "barriers" are delaying the regime transition. These impediments are multifaceted, encompassing policy, market and user choices, and technological dimensions. There is non-linear dynamics between these interconnected regime dimensions that mutually reinforce each other. When examining the dynamic between price and technology, policy and technology, policy and pricing, and all three combined, co-evolution is obvious. Another noticeable dynamic at this level, particularly at the policy level, is path dependency. Regulations, standards, and certifications are all based on the dominant status quo of grey hydrogen production regime. These dynamics make it difficult for water electrolyzers to diffuse and replace the stable regime.

4.3 Niche Level

In order to understand the drivers and barriers, as well as the dynamics of the landscape and regime, niche dynamics play an important role. In previous sections of this chapter the dynamics and drivers and barriers of the transition were analyzed and discussed. This section will then use strategic niche management framework to examine the dynamics in the niche level of green and blue hydrogen in the Netherlands.

4.3.1 Comparative analysis on expectations in each level in the green and blue hydrogen niches

The typology proposed by Yang et al explained in section 2.3.3 will be used to analyze and further evaluate the expectations for green and blue hydrogen niches, as well as to understand the dynamic.

4.3.1.1 Landscape-Level Expectations:

Exploring how landscape changes are interpreted by niche and regime actors is a vital component in bringing about the transition. When these individuals recognize and predict that landscape developments will continue to exert pressure on the regime, the regime's resilience and stability may be questioned by regime insiders, resulting in tensions and cracks within the regime. Niche actors, on the other hand, will continue to seek chances, as well as improvements and support for their preferred niche, in the goal of breaking through and substitution of the regime. This emphasizes the significance of considering the analysis of landscape level expectations.

At the landscape level, there is broad alignment in the Netherlands on the transition to zero-carbon hydrogen. There are two evidence to support this. First, considering the Netherlands landscape there are many government policies and initiatives concerning hydrogen's role in the Netherlands' future energy transition. As already mentioned in the landscape analysis (section 4.1) Government strategy on the hydrogen, along with climate agreement, the National Energy and Climate Plan (NECP), The Climate Plan all send a clear message of the need to the change toward a zero-carbon energy system with hydrogen playing a key role. Second, these landscape developments are not only limited to the national landscape but also on the European levels these signals that call for changes and transition in the energy system can be observed. several funding and financial incentives available in different levels and the support for hydrogen transition. This can be seen as the result of several strategies published by policy makers in European level. In European level it is seen as a key priority to achieve green deal (*A Hydrogen Strategy for a Climate-Neutral Europe*, 2020). There are also funding schemes that supports introduction of hydrogen on the European level. Some examples are Funding for demonstration projects available on the European landscape through a variety of large-scale programs (Gigler & Marcel, 2018). The FCH JU (Fuel Cell and Hydrogen Joint Undertaking) is working on a key initiative involving fuel cells and hydrogen, as well as the TEN-E (Energy) and TEN-T (Transport) programs for hydrogen infrastructure (Gigler & Marcel, 2018). TSO2020 synergy project run by Gasunie, Tennet, Akzo and partners in the Netherlands, as well as the H2Benelux project for the implementation of a range of hydrogen refueling points (Gigler & Marcel, 2018).

As a result, regime and niche actors perceive hydrogen as a key component of the future potential zero-carbon energy system in the Netherlands. Regime actors are clearly feeling pressurized to respond to the threat exerted from the landscape that seeks changes in the current energy production systems. They perceive that hydrogen will be an indispensable part of the future energy system and changes to adapt their current production systems accordingly are necessary.

However, it is important to note that, while zero-carbon hydrogen (which can be either blue or green hydrogen, and not necessarily green hydrogen produced by water electrolyzers) is perceived to be a key component of the future energy system, it is still unclear whether green hydrogen or blue hydrogen will receive more attention and investment. Examples of this ambiguity can be found, for example, in the government's hydrogen strategy, which occasionally refers to "zero-carbon hydrogen" as a crucial enabler of change while emphasizing "green hydrogen" in other areas. There appears to be a need for a more structural and clear vision for the landscape's support of green hydrogen and water electrolyzers.

4.3.1.2 Regime-Level Expectations:

Another level of expectation to evaluate is how actors view the regime's stability in responding to internal and external forces. External pressure refers to the pressure applied by landscape developments that have a destabilizing character, while internal pressure refers to potential tensions and fractures caused by internal regime dynamics that may cause regime players to question the regime's stability. This level of analysis is significant because if niche and regime actors expect and anticipate that the regime will not be able to maintain its stability in the face of destabilizing pressure, it may cause both regime and niche actors to doubt the stability and contribute to either seeking alternatives or niche development.

In the case of the zero-carbon hydrogen transition, regime and niche players have begun to call the regime's stability into question and are looking for alternatives that may offer niche acceleration chances. Hydrogen is viewed as a key component of the future by actors. Landscape pressure is widely believed to be severe, and there is an urgent need for the Netherlands to meet with its commitments, culminating in an urgent transition to a zero-carbon economy (low-carbon, maybe, at first stages). This claim is verified in the interviews as well, with some respondents predicting a future market for hydrogen in the future energy system fairly certainty. They believe that in the future there will be a market for hydrogen: “I'm 99 percent certain that there will be a market, but it's a market that will be created. (interviewee #2)”. They also believe that this transition is urgent and also relate it to the commitments of the Netherlands and other countries to international agreements especially Paris agreement: “Yes, that will absolutely be a market for green hydrogen in the future, because like most countries in the world have signed the Paris agreement. So they want to reduce carbon dioxide levels, emission levels to zero in 2050 or let's say around 2050, maybe in 2060. So, yes, there will be certain to be a market for a green hydrogen. Interviewee #1”

The formation of various coalitions and initiatives to take concerted activities and steer the desired modifications of diverse actors can also serve as evidence that the regime is under internal tension, and it can be a sign of fractures in the regime is visible. Both regime and niche actors perceive that the regime will be destabilized and that the threat to current production methods is significant. As described further in the network building analysis (section 4.3.3), various advocates are preparing to provide answers, resources, and shape the transition in accordance with their companies' aims and plans.

It can be concluded that niche and regime actors have a broad alignment of expectations that the regime, influenced by landscape pressure and internal tension in the regime, is destabilized and actors are seeking alternatives to diversify their energy production method with a shift away from unsustainable fossil fuels and toward more production of low or zero carbon hydrogen. As previously stated, this anticipation is corroborated by interviews and patterns in network development by various beneficiaries.

4.3.1.3 Niche-Level Expectations:

In this study, niche level expectations are required since there are two niches, blue and green, that have different supporters and ways of articulating expectations in terms of depth (quality) and breadth (quantity). Although from preceding discussion it can be noticed that regime and niche actors expect the landscape pressure to be persistence and they also expect that regime will be destabilized based on internal and external pressures, an important point of departure in these actors' viewpoints is the debates over whether it is blue or green hydrogen that will be preferred or has the potential to substitute or modify the regime.

Blue Hydrogen has broad alignment in terms of regime and niche actor alignment. A variety of factors have played a role in this. To begin, unlike water electrolysis technologies, which are based on renewable energy and competes with other carbon-reduction technologies, blue hydrogen is based on current fossil-fuel-based energy systems rather than renewable energy. The technological readiness of blue hydrogen, on the other hand, is very high. In the feedstock sector, primary reformer technologies are already in use. Established infrastructure and supply chains can be used by this technology. Finally, the cost of producing blue hydrogen is predicted to be less than a third of the cost of producing green hydrogen using present technologies. These concerns were also shared by interviewees. Interviewee #1 believes that big multinational grey hydrogen production companies are not inclined to invest in green hydrogen technology due to its low profit margins and different business models that they need. Interviewee # 3 believes that large firms and manufacturers of grey hydrogen to prefer blue hydrogen and leave green hydrogen investment to the market and future.

However, not all regime actors, share the same expectations with green hydrogen niche advocates that water electrolyzers are the promising technology for this transition, at least in the short term. The reasons for this are manifold. One very specific reason is that the three are still challenges on several dimensions left to be decided on. There are still debates on the supply of renewable energy and its price, mass production and upscaling challenges related to water-electrolyzer, and also commercial and financial barriers (Gigler et al., 2018). Green hydrogen produced in North-western Europe costs two to three times more than blue hydrogen at the moment (Gigler et al., 2018).

However, there are predictions that this price disparity will narrow (Gigler et al., 2018) but it is not certain at the moment since it relates to the price of electricity and other factors. The interviewees also share the same opinion as one of the interviewees states "Not everyone, but a lot of people see that it is impossible to do that (introduction of water-electrolyzers) because it will take too long to have the legislation to do the changes, the rollout, et cetera. So, we will run out of time. So, we have to buy ourselves time to reach the goals and we buy ourselves time by CCS. And so, some governments and some people subsidize it or support it. Some people don't want to. I think we need it." (Interviewee #9). He also emphasizes that that it is not really clear if green hydrogen production will be developed fast enough to meet the requirements of the carbon-reduction goals

It is conceivable to argue that regime and niche players have selective alignment expectations in the green hydrogen niche in the example of hydrogen generation in the Netherlands. This alignment can be considered selective because some multinational and grey hydrogen production companies are also working on green hydrogen production (Shell and Engie, as two examples) and have started various projects. This could indicate that actors believe the regime is destabilized for future changes, but there is still uncertainty over whether green hydrogen technologies can be adopted and spread as the preferred option.

Alignment Patterns:

This part brings to a close the methodical integration of earlier analysis and discussion. After completing the assessment of actors' expectations at three different levels and three degrees of breadth at each level, it is possible to draw conclusions about how expectations between niche and regime actors are aligned in two separate niches of blue and green hydrogen. This analysis is summarized in Table 4.

Table 4: Expectation Alignment Patterns

	Breadth of alignment between niche and regime actors in the landscape level	Breadth of alignment between niche and regime actors in the regime level	Breadth of alignment between niche and regime actors in the niche level
Green Hydrogen Niche	Broad	Broad	Selective
Blue Hydrogen Niche	Broad	Broad	Broad

According to the analysis, the blue hydrogen niche is characterized by a strong alignment between niche and regime actors. This is primarily because blue hydrogen is based on current fossil-fuel-based energy systems rather than renewable energy, that it can leverage existing infrastructure and supply chains, and that it has a high level of technological readiness. The green hydrogen niche, on the other hand, is aligned in a medium strong way. Although some regime actors are optimistic about the future of green hydrogen technology, and niche actors are beginning to imagine the future regime they want to create as an alternative to the mainstream regime, several changes in supply and current infrastructure are required for green hydrogen to be aligned with regime actors' expectations.

4.3.2 Comparative analysis on learning processes in the green and blue hydrogen niches

Blue hydrogen production technologies, grey hydrogen production technologies and CCS, have been in use in the Netherlands for quite some time, although separately for different applications. They have been used and tested several times in different projects (interviewee #11). This is technically feasible because it uses existing industrial infrastructure and requires only minor modification (interviewee #11). This long history of usage indicates that technology has been thorough several learning processes on multiple dimensions. On technological and design dimension it can be argued that main technologies have been extensively used for decades, only small modification on the application of the CCS in hydrogen technology is necessary which is believed not to be a big challenge (interviewee #11). This can also be regarded the case for infrastructure and maintenance network and industry and production networks. Technologies involved, especially CCS due to its application in several energy transition applications, have been for long subject of several societal and environmental debates and regulatory and governmental policy debates. These developments and long use of technology indicates that assumptions on different dimensions of learning have already been made resulting in a more in-depth and second order learning processes.

Water electrolysis technologies, on the other hand, are experiencing some difficulties in the Netherlands. The process of designing and manufacturing electrolyzers is still in its initial stages. The market is small on a MW scale, and only a few companies manufacture electrolyzers. Production procedures aren't yet automated there's a lot of manual labor, and the supply chain isn't yet well-organized. To achieve the requisite cost reductions and increase production volumes to GW levels, a stroke of creativity is required at both the technical and automation and optimization levels of the supply chain (Stevelink & Pukala, 2020).

Electrolysis technology is a subject in which companies situated in the Netherlands have necessary expertise and experience. These parties can source advanced materials and components and combine them into stacks or systems when they work together. However, currently, the playing field is disjointed. Too much innovation and knowledge development take place in isolation. It doesn't help that just a small percentage of the potentially relevant enterprises are already involved in the existing electrolyzer (components) manufacturing chain (Stevelink & Pukala, 2020).Another important factor that impedes learning in green hydrogen technology is that Few significant corporations, such as Siemens, Thyssenkrupp, Hitachi, Hydrogenics-Cummins, ITM Power, Areva H2Gen, McPhy, or Sunfire, presently monopolize the electrolysis market on the European level (Suurs et al., 2020). With all these things considered it seems to be very difficult for new entrants to grab the knowledge and improve the learning process:(Suurs et al., 2020). The present manufacturers preserve their intellectual property and keep their sources restricted for obvious reasons. The disadvantage is that novel entrants, even potentially inventive suppliers, have a difficult time breaking into this market (entry barriers) (Suurs et al., 2020).Interviewee #10 highlights this preference and links it to the fact that since there are not enough subsidies and policy support it makes sense for producers to keep this intellectual property close and not share it freely with other entrants.

According to the data shown above, water electrolyzers lack the required learning processes in multiple dimensions, and the majority of learning processes are first order rather than second order learning processes. Being in the early stages of development and lacking an organized and connected network of developers makes learning on technical and design specifications, industry and production networks, and infrastructure and maintenance networks very difficult.

4.3.3 Comparative analysis on network-building in the green and blue hydrogen niches

The hydrogen economy is evolving at a rapid pace both in support of blue and green hydrogen. One key reason for growth is because hydrogen may be used in a range of applications, and various industries may now be targeting hydrogen use. As a result, new organizations are creating alliances and proposing strategies to deploy hydrogen in a wide range of applications, from the built environment to transportation and industry.

Over 250 firms and organizations are presently exploring hydrogen-related activities, according to a recent inventory conducted for the Netherlands Enterprise Agency (RVO), the Ministry of Economic Affairs and Climate Policy, and FME (the trade association for the technological-industrial sector (Gigler et al. 2018). Large corporations, small businesses, network managers, knowledge institutes, regional organizations, municipalities and provinces, ministries, and civil society organizations have all expressed an interest in hydrogen technology and a desire to participate actively and financially (Gigler et al. 2018). A large number of regional plans (for example, for the Northern Netherlands, the provinces of Zuid-Holland, Limburg, and Gelderland, the North Sea Channel zone, and the Zeeland Delta (SDR)) have also been established, each of which defines a future role for hydrogen (Gigler et al. 2018).RVO's innovation calls-for-tender, which were conducted at the request of the Top Sector Energy, brought together a diverse group of stakeholders who are now collaborating on new technologies (Gigler et al. 2018).

Blue Hydrogen Network Building

Due to its excellent expectation articulation and clear strategic aims, the blue hydrogen network, initiatives, and coalitions have been developed by attracting numerous industries. This network's common strategic goal is to enhance social acceptance of hydrogen produced utilizing CCS technologies. This is a network of existing fossil fuel corporations who want to employ CCS to capture and store the CO2 produced by their unsustainable production techniques. To understand what constitutes the blue hydrogen network, we must first provide a quick review of CCS, the primary and most important technology proposed for usage, as well as its special characteristics.

CCS is not a new technology; it has been used for a variety of purposes other than blue hydrogen technology. CCS is one of the primary end-of-pipe solutions that incumbent fossil fuel firms have long suggested to limit carbon emissions.(cf, (Geels, 2014) for "clean coal" discourse , or (Raven et al., 2016)) . The role of CCS in the case of blue hydrogen has been underlined by its supporters. As a result, the key supporters and network have many similarities with fossil fuel businesses that previously shared and articulated the expectation of a "low-carbon" energy system. Having said that, it is now evident that the primary technology advocates for blue hydrogen technology are the government, as a fast way to fulfill its international commitments, as well as large multinational-national oil corporations and producers of grey hydrogen, for obvious sunk investments.

Green Hydrogen Network Building

Green hydrogen network in the Netherlands can be divided into some main group of actors: 1) International oil and gas companies (Shell (Shell and Eneco project) and Bp for example) 2) utility companies 3) renewable energy developers 4) companies that are potential consumers 5) chemical companies (Nouryon (now named Noubyon) as an example) north and a lot of initiatives especially in the north (new energy coalition) , BioMCN , North H2 (not active), (interviewee #2). (Interviewee #4) (interviewee #1). On small scale this production can also be done by communities who invest into a small electrolyzer producing electricity from solar PV or wind turbines that are somewhere in the vicinity (interviewee #1). Network of suppliers of electrolyzers on the globe level also is dominated by companies like Siemens, thyssenkrupp, Hitachi, Hydrogenics-Cummins, ITM Power, Areva H2Gen, McPhy, and Sunfire (Suurs et al., 2020). They collaborate together with a select group of suppliers. Most are SMEs, such as McPhy, Areva, Hygs, h-tec, NEL, Teledyne, Plug Power (Suurs et al., 2020).

The challenge for the Netherlands, is that although approximately half of all electrolyzer manufacturers, as well as the majority of their component suppliers, are based in Europe (Suurs et al., 2020) the market remains too limited, with activities fragmented and underutilized (Suurs et al., 2020). Another important challenge in network building is that Prospective supply chain partners usually overlook one other's presence, let alone their desires and capabilities (Suurs et al., 2020). Because of this lack of clarity and effective network building , common education opportunities are limited, and the requirement to connect diverse types of expertise is greatly hampered (Suurs et al., 2020) .Interviewee # 3 also points out lack of well-organized network and collaboration between different projects “Although there are a lot of companies that can potentially play a role in the supply chain but they are not well organize and they are at a disadvantage when compared with international competitors (interviewee #3)”.

The green hydrogen network is broad, and it includes a diverse range of stakeholders. The presence of oil and gas firms like Shell and BP demonstrates that it is not only renewable energy companies that are typical advocates for green technologies, but also "outsiders "in strategic niche management terms. This involvement of outsiders can aid in the learning process. The difficulty with this network appears to be its depth. Because they are not effectively structured to share information and push for their desired outcomes, this niche loses the ability to attract the required resources to nurture and empower itself.

4.3.4 Discussion and Conclusion on Niche Level Dynamics

In this section, I will highlight the most significant barriers in the niche level of green hydrogen production in the Netherlands. I can then answer the third sub research question of this thesis by evaluating developments at the niche level. The third sub-question is as follows:

How do the blue hydrogen niche and the green hydrogen niche compare and contrast in terms of expectations, learning processes and network-building?

In the last section, I examined the dynamics of the niche by focusing on three internal processes of the niche. Some of the barriers associated with these procedures are revealed as a result of the investigation. These barriers are summarized in Table 5.

Table 5: Nihce Level Barriers

Expectation Barriers	Niche Level : • Uncertainty on multiple level about technical, financial, upscaling, supply of electricity, and the demand of hydrogen
Learning Barriers	• Initial stage of design and manufacturing • Isolation of knowledge development • Monopoly of technology and knowledge by few corporations
Network Building Barriers	• Depth of network: Lack of well-organized network

As stated in the introduction to this chapter, it is possible to analyze the dynamics at the niche level and have a broader understanding of potential barriers to water electrolyzers spreading as a path breaking innovation by analyzing three internal processes suggested by strategic niche management: articulation of expectations, learning processes, and network building processes. According to the findings of this study, there are several barriers in these processes that make it difficult for water electrolizers to diffuse. These impediments were identified and summarized in table 5. However, these barriers do not act in isolation; rather, it is the interaction between them that might lead to implementation failure. A discussion of these barriers is provided below to help to understand how they interact with one another.

Despite the presence of a destabilized regime, At the niche level, expectations for the future of water electrolysis is not broad and commonly shared, niche and regime players are dubious if green hydrogen produced by water electrolyzers will play a key role as the primary fuel source for the future hydrogen economy. There are several uncertainties about the technical capacity of water electrolyzers and its upscaling, future price of hydrogen produced by them, cost and availability of renewable energy on the supply side, the applications on the demand side; all of these problems make water electrolysis technologies less appealing to actors on several levels. Not articulating a shared, positive and clear expectation with clear promises of the future makes the niche less attractive for important actors to step in and support the niche. This will then lead in a network of actors that are not well aligned which this can hamper attraction of money and resources and learning processes. However, it should not be perceived that one of these barriers causes the other, rather it is a loop of effect on each other, that enforce or weaken the transition.

Chapter 5: Conclusion

In this section the main research question will be answered. One advantage of employing a multilevel perspective is that it allows you to look at transition studies not just as a simple cause and effect, but also by taking into account the linkages of multiple reasons that feedback on each other or “circular causality”. Using such an analytical framework, we can identify not only the barriers and drivers at each individual level of landscape, regime, and niche, but also how these levels interact with one another. The alignment and timing of several processes at various levels impacts the fate of the technology. This will result in an answer to the main research question and then the research limitations are reflected upon and this chapter will end by recommendations for future research.

5.1 Answer to the main question

The main research question is:

what are the barriers to the implementation of water electrolyzer in the Netherlands.

Water electrolyzers, as detailed in the preceding chapter, face implementation challenges on numerous levels. These barriers have already been adjusted and elaborated at each level of landscape, regime, and niche. However, Transitions do not succeed or fail as a result of linear cause and effect; rather, they are the result of non-linear dynamics. The answer to the main question, then, is not a list of obstacles that act in isolation, but rather barriers that interact. As a result, answering the main research question needs further elaboration and discussions about these non-linear dynamics and their interaction. This elaboration and discussion with the aim to answer the main question is as follows.

Landscape pressure is a key factor for a successful transition. This study showed that in the landscape level, global and European landscape developments in energy supply security and climate change, as well as Dutch climate movements put the pressure on the current grey hydrogen production regime and open up a window of opportunity for sustainable production methods of hydrogen and specifically green hydrogen production in the Netherland. However, this pressure did not result in a broad expectation in regime and niche actor in the niche level about the future of water electrolyzers as the preferred technology for the transition. It can be argued that although support programs for fuel cells and hydrogen infrastructure send a clear message that landscape developments and expectations for hydrogen usage are quite high, structural and specific support for the case of green hydrogen production and water electrolysis was not observed in policy landscape, they urge for a carbon reduction that does not necessarily mean a transition to green hydrogen production, this can also be achieved by other carbon reduction techniques such as using CCS technology. The problem is that movements and events in the landscape point out the need to a zero-carbon hydrogen energy system, but these supports are at some point contradictory toward blue and green hydrogen niches, leaving it unclear and difficult to draw conclusions about how the future of green hydrogen production is perceived in the landscape.

Another critical component of driving transition is presenting investors and customers with clarity about investment decisions. Certainty is necessary for the upscaling; this will be required to cut down the investment needed in the technology in initial stages. However, study has revealed that there are obstacles to the clarity about the investments of water electrolysis, such as a lack of a defined long-term action plan, a lack of a clear regulatory framework, and a lack of certification that complies with European regulations. These ambiguities and lack of clarity will be a strong deterrent to investors, with the majority of those interested waiting to see what occurs. This uncertainty is exacerbated by lack of fiscal incentives that fit the purpose of the introduction of water electrolyzers on policy dimension. Although there are funding schemes such as SDE++, but is revealed that these funding scheme, with the focus on the CO2 emission ranking, is not sufficient and do not fit the purpose of the introduction of water electrolyzers.

This study showed that water electrolyzer in the niche level is experiencing a hard time escaping its niche level. This, however, is not mainly and only due to barriers in niche internal mechanisms or barrier factors on the regime level but rather a loop of circular causes (Figure 11). This circularity can be explained that lack of a mature technology in water electroylzer niche that requires innovation to scale up and become economically viable , without the support of a strong network and lack of clear expectations ,limits policymakers from launching substantial subsidy and financing programs and regulatory frameworks; yet, this lack of policy support will affect the niche actors expectations of the future of the technology and make them unsure about investment in the water electrolyzers. This also will affect building powerful networks to support and lobby for the needed resources to nurture the niche. These feedbacks point to a chicken-and-egg problem, making adoption particularly difficult.

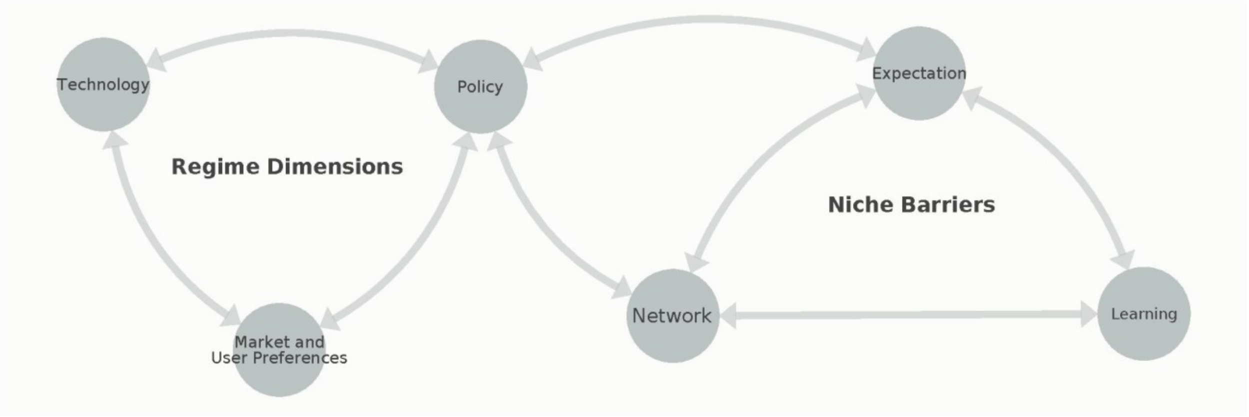

Figure 10: Barriers Interaction

In conclusion, if the government's primary goal is to assist the development of green hydrogen production technologies, it is suggested that active shielding to ward off selection pressures in selection environments is required in the case of green hydrogen. For example, one feasible recommendation on the technological dimension to protect the water electrolyzer technology is to implement temporary exemptions from existing co2 emission restrictions in the early stages to aid in the maturation of the technology. On a scientific level, the government can also implement additional water electrolysis-specific R&D support schemes. And finally, on policy level lobbying for explicit water electrolysis in political level can help to more actively shield water electrolyzers' niche. Specific attention should be also paid to the network building of active networks and integration of supply chain. This can help to facilitate not only the learning processes but also attraction of resources to the niche.

5.2 Research Limitation and future research:

The objective of this master's thesis is to shed light on potential barriers to the adoption of water electrolyzer technology. This research yielded useful results, especially when it came to pinpointing specific barriers. However, due to the sophistication of these barriers and time constraints, this thesis is unable to make explicit recommendations on how to proceed. There are two primary results from the study that necessitate further investigation into how to overcome these limitations.

1. In the Netherlands there are currently two prominent niches, blue and green hydrogen production that are thought to have the potential to diffuse and be used as the mainstream hydrogen production methods. A further research needs to be done to further understand this interaction and analyze if these two niches have complementary interactions or there is competition between these two niches.

2. By analyzing each level of landscape, regime and niche in this study, some barriers are outlined. It is suggested that for each specific barrier there can be a research to understand to root causes and how to overcome the mentioned barriers.

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Appendix

Interview Protocol

Based on the study's conceptual framework, a combination of desk research and semi-structured interviews with informants, experts, and respondents in the field of blue and green hydrogen production in the Netherlands were conducted. Due to the restricted time for the interviews and the knowledge of the experts, two sets of questions were designed to assist in gathering the essential data on various levels of this study. One set of questions was created for landscape and regime information, and the other set was for niche information. In the event that the respondent was thought to have knowledge at a given level, questions about their expertise were also asked.

During the interview, four essential interview questions were asked. 1) What are your thoughts on the future market for green hydrogen? 2) How is large-scale water electrolysis production supported? 3) What role do you envisage grey hydrogen producing actors playing in the transition to green hydrogen? 4) What, in your opinion, are the barriers to the application of water electrolysis? Follow-up questions were asked in response to the answers to the major interview questions. The interviews ranged in length from 32 to 45 minutes, with an average of 38 minutes. All interviews were recorded and transcribed with permission for additional data analysis.

Interview Structure and questions

Introduction	Part 1 : Thesis Explanation and the necessity of the interview • Thesis goal • Explaining that thesis is speciffically looking at baariers to the implementation of water electrolysis Part 2 : Inquire whether the interview can be recorded and whether the material should be used in the study.
General Questions	• Leading Companies • Market availability of green hydrogen
Landscape Questions	• How do they see the future of green hydrogen and why
Regime Questions	• Subsidies that support large scale production of water electrolysis • R&D subsidies for water electrolysis • Readiness of the technology • Regulatory framework • Pricing
Niche Questions	• Questions dealing with expectations. • Social Networks Formation • Questions dealing with Learning processes.
Concluding Questions	• General concluding remark about barriers and solutions

List of Interviewees

Number	**Reference in the text**	**Position**
1	Interviewee #1	Manger at TKI New Gas
2	Interviewee #2	Energy Transition consultant at Recoy
3	Interviewee #3	Researcher / Advisor at TNO
4	Interviewee #4	Manager at H2 Platform
5	Interviewee #5	Researcher at Centre for Energy Economics Research (CEER)
6	Interviewee #6	Energy Transition consultant at Stichting kiEMT
7	Interviewee #7	Manager ENGIE
8	Interviewee #8	Advisor at Shell
9	Interviewee #9	Manager at HyGear
10	Interviewee #10	Manager at Nouryon
11	Interviewee #11	Project manager at Deltalinqs