Hydrogen Filling Stations:

A sociotechnical systems analysis of implementation and transition

By Remco van den Heuvel

Master's Thesis for the Spatial Planning programme

Specialisation Urban and Regional Mobility

Nijmegen School of Management
Radboud University

July 2020

Colophon

Title:	Hydrogen Filling Stations: A sociotechnical systems analysis of implementation and transition.
Author:	Remco van den Heuvel
Student number:	s1044113
Submission date:	July 2020
University:	Radboud University Nijmegen Radboud School of Management
Supervisor Radboud:	Dr. Sander Lenferink
Internship location:	Witteveen+Bos
Supervisor internship:	Wim van den Berg, MSc

Radboud University

Witteveen+Bos

Preface

This thesis is the completion of my master's degree in Spatial Planning at the Radboud University Nijmegen, specialising in Urban and Regional Mobility. The subject of the thesis is hydrogen filling stations and the research has been conducted during an internship at Witteveen+Bos. From a young age I have been interested in mobility, and cars specifically, as well as being interested in sustainability from a later age. This thesis forms the combination of these personal interests with my major Spatial Planning by combining sustainable mobility with intervention in our environment.

I would like to thank several people who have helped me during the research process and who have helped me to successfully complete my master's degree.

First of all, I want to thank my supervisor at the Radboud University, Sander Lenferink, who helped me with his feedback on my thesis and his guidance during this process. Our meetings encouraged to reflect critically and improve upon my work.

Second of all, I want to thank my supervisor at Witteveen+Bos, Wim van den Berg, who also helped me with his feedback and critical reflection. I also want to thank the other colleagues who were part of the group Gezonde Leefomgeving at that time. Our regular meetings from home helped with providing structure as well as staying motivated and productive during this strange and troubled Corona time. Additionally, I also want to thank Fenna van de Watering for helping me get in contact with respondents and her contributions to this research.

Finally, I want to thank all the respondents who greatly helped me and told me everything I needed to know about hydrogen with great passion. Without them this research would not have been possible.

I hope you enjoy reading this master's thesis.

Remco van den Heuvel
Utrecht, July 2020

Summary

The world as we know it is affected by climate change. Mobility has a large part in it. Therefore, more sustainable types of transportation are being developed. One of these is based on hydrogen in the form of Fuel Cell Electric Vehicles. These use a fuel cell to convert hydrogen into electricity and electric motors to drive but they also need infrastructure. Therefore, hydrogen filling stations are being developed but there a small number of them in the Netherlands. These circumstances create a lock-in situation, vehicles are not bought because of a lack of filling stations and filling stations are not built because of a lack of vehicles or customers.

This study focussed on the implementation of these hydrogen filling stations and studied these as a sociotechnical system. This was done by researching three components of the sociotechnical system: physical system, task and structure. The research is seen in the larger context of a hydrogen mobility transition. Hydrogen filling station implementation might limit this transition and should therefore be done as good as possible. Therefore, barriers that limit this implementation and opportunities that might solve these barriers can be identified. This comes to the main question: *What barriers and opportunities that limit or improve hydrogen filling station implementation can be identified in its social technical system within the hydrogen mobility transition in the Netherlands?*

This was researched by conducting desk research and performing nine expert interviews. Respondents from different companies and with various backgrounds were interviewed in order to gather enough data and perspectives. The most important finding are as follows. The physical system or technological side can complicate the implementation through technological complexity and the choices made regarding on-site or off-site production, transportation method, multi-fuel capacity and size. The tasks the hydrogen filling station must fulfil were found to be related to economic, safety, location and social factors and must achieve good: practical usability, convenience, affordability (price) and accessibility (location). Regarding structure, based on power, legitimacy and urgency it can be concluded that actors from the state sector (as defined in the theoretical framework) score high on these parameters and can therefore play a large role in improving the implementation of hydrogen filling stations. Eventually the interviews also resulted in a large list of barriers and opportunities. The largest barriers were the inability to complete the business case, difficulties and delays regarding permits and legislation (due to unfamiliarity) and a lack of vehicles. Several important opportunities to solve these barriers were distinguished of which two are the most important. The first is better and more information sharing between actors. The second is lowering the hydrogen price and stimulating the production and sale of vehicles with improved subsidy.

The importance of the hydrogen price proves that the implementation of hydrogen filling stations can not be seen without the context of a larger hydrogen transition. Therefore, a more comprehensive approach is needed.

Table of contents

1 Introduction

As has been made clear quite extensively in the past decades, climate change is a huge problem that threatens the world as we know it. The Paris Climate Agreement is a recent example of the world's dedication to tackle climate change. It shows that the world must act quickly. The EU, for example, is committed to halt climate change by reducing greenhouse gas emissions by at least 40% by 2030 (European Commission, n.d.). A part of modern society that emits a large amount of greenhouse gases is the mobility sector. This sector is still dominated by cars with combustion engines that burn gas or diesel fossil fuels (Apostolou & Xydis, 2019). In the past years three important new concepts have been introduced in the car mobility sector. First of all, there has been an introduction of several types of hybrid cars. These use a combustion engine and electric motors, reducing emissions but not completely eliminating them. Some of these hybrid cars have the ability to have their batteries charged externally (Wilberforce et al., 2017). The second new concept that has been introduced is that of battery electric vehicles (hereafter called BEVs). These cars use electric motors and batteries and must be plugged in to recharge these batteries. Lastly, another new concept has been introduced in 2014, namely Fuel Cell Electric vehicles (FCEVs). These FCEVs use a fuel cell to create electricity from hydrogen and drive using this electricity (Apostolou & Xydis, 2019).

Electric vehicles are becoming more and more common on the Dutch roads. In 2019 for the first time a BEV (Tesla Model 3) was the most selling car in the Netherlands. Tesla sold almost 30.000 Model 3's which account for 6,7% of the total number of sold cars in the Netherlands in the year 2019. In the month of September 2019 itself this was an even higher percentage: 15,5% (NOS, 2019). The amount of EVs sold will likely increase in the future. In 2017 the Dutch government made the statement that in 2030 all new cars must be emission-free (Huygen et al., 2018). This increase in new EV's asks for well-functioning public charging or refuelling infrastructure. The market for charging infrastructure is evolving quickly which causes uncertainties. For example, it is not clear which type of charging is needed. Specifically, there are fast, slow, wired, wire-less, public and private charging for example (Huygen et al., 2018). This uncertainty could make it difficult to choose the right options for infrastructure. While there are relatively many BEV's on the roads, the number of FCEVs in the Netherlands is still rather small. In March 2020 there were 237 FCEV cars and 251 Fuel Cell vehicles in total (including buses and trucks) present in the Netherlands, according to H2Platform (H2Platform, 2020).

In the beginning of 2020, it has become clear that there are several disadvantages to BEVs. Due to the increased number of BEVs that need to charge in the evening, measures must be taken to prevent blackouts. One electric vehicle charging its batteries can use the same amount of electricity as 10 households. This means that when 10 of these vehicles are charging at the same time in one street suddenly the electricity consumption is increased tenfold (Voermans, 2020a). Another disadvantage is the range of BEVs and the time it takes to charge them. This has become evident when Dutch BEV owners were left waiting for hours for a spot at the fast charger in Germany in February 2020 (Voermans, 2020b). The issues described will not affect a FCEV because filling the hydrogen tank takes only several minutes. Because of these advantages of FCEVs and disadvantages of BEVs the former might be argued to be a good alternative to fossil fuels while conventional BEVs might turn out to be only a temporary solution, at least for long distance or heavy-duty mobility (Apostolou & Xydis, 2019). It must be mentioned that forming an alternative does not mean replacing BEVs. The two types of vehicles can coexist and appeal to different markets, similarly to gasoline and diesel vehicles do now.

However, before it can be a viable alternative, the essential infrastructure must be put into place. This means building facilities to generate green electricity, creating hydrogen from this green electricity, creating infrastructure for transporting hydrogen and creating the hydrogen filling stations themselves (Apostolou & Xydis, 2019).

Making a transition towards hydrogen mobility has also been mentioned in the 2019 Climate Agreement made by the Dutch government. During the first quarter of 2020 there only were three public and six non-public hydrogen filling stations in the Netherlands. This number was increased to a total of 5 by June 2020. The number of filling stations will be increased in order to reach the goal of 50 filling stations set for 2025. Together these 50 filling stations will be able to supply 15.000 cars with hydrogen (RWS Duurzame mobiliteit, n.d.). The other side of the problem is the number of hydrogen cars. There are very little hydrogen cars currently in the Netherlands. These two make a self-sustaining problem, which will be called a lock-in situation from this point onwards. The Dutch government currently has policy in place that could help to solve this lock-in but there might be chances for improvement. Further policy changes might be useful to account for barriers, such as slow permitting processes, that might hamper or slow down the transition. Furthermore, there might be opportunities that can be taken and that can help improve the transition and hydrogen filling station implementation. The implementation of filling stations can have spatial implications which need to be further explored so that these can be taken into account in this process. Furthermore, it is possible that the way we might fill our hydrogen tank at a gas station will be different in the future than what is currently customary. Speeding up and improving this potential transition towards sustainable hydrogen mobility is beneficial because the limitation of climate change needs to happen as soon as possible. The sooner alternatives to fossil fuels are made viable, the sooner this sector reduces its contribution to climate change.

1.1 Research aim, research objectives and research questions

1.1.1 Research aim and research objectives

The research aim of this master's thesis is exploratory and descriptive in nature. Firstly, because the transition seems to be in a very early phase and secondly there is not much literature available on this specific subject. Therefore, this is the most suitable research aim for this research. The research objectives can be described more concretely. The objectives are (1) gathering of both theoretical and empirical data in one place, (2) analysing this data and from this analysis (3) making recommendations for improving hydrogen filling station implementation and indirectly the context of the hydrogen mobility transition. Improving the hydrogen mobility transition means solving barriers and mitigating the lock-in situation. This research also aims to (4) provide insight into the technical side of hydrogen filling stations and (5) more extensive insight into the roles of relevant actors and their roles in the market. Eventually the outcomes of this research could possibly contribute to a better or faster transition and therefore help limiting climate change but this is not directly in the scope of this research. Further research would be needed to reach that goal. These aims are brought together in several research questions which are introduced in the next section. The research does not aim to investigate the viability of hydrogen mobility and does not aim to compare this viability with for example electric vehicles or contemporary fossil fuel powered vehicles. Research into those subjects would be valuable, but too large for the scope of this thesis. The research aims specifically on the implementation of the infrastructure needed for hydrogen mobility.

1.1.2 Research questions

In order to achieve the afore described research aims and objectives, a number of research questions have been formulated resulting in a main question that will be answered by four sub questions. The common thread in this research will be supplied by the components of sociotechnical systems defined by Oosthuizen and Pretorius (2016). These are structure, people, physical system (technology) and tasks. The component of people will not be explored in this research because the focus lies on actors in the implementation process and not on the end users (defined as the people component) who will drive the cars or use the filling stations. These components are also embedded in the sub questions and will help in solving the main research question. Further explanation on sociotechnical systems can be found in the theoretical framework.

Main question: What barriers and opportunities that limit or improve hydrogen filling station implementation can be identified in its sociotechnical system within the hydrogen mobility transition in the Netherlands?

Sub question 1: What role does the physical system play in the implementation of hydrogen filling stations in the Netherlands?

Sub question 2: What role does the task component of sociotechnical systems play in the implementation of hydrogen filling stations in the Netherlands?

Sub question 3: What role do structure and relevant actors play in the implementation of hydrogen filling stations in the Netherlands?

Sub question 4: What are the opportunities and barriers regarding the implementation of hydrogen filling stations in the Netherlands?

This master thesis contains six chapters and is set up as follows. A theoretical background will be provided in Chapter 2 and the research methods will be explained in Chapter 3. The questions above result in two chapters (Chapter 4 and 5) in this master's thesis that have a logical order. After these steps the barriers and opportunities for improving filling station implementation can be explored. Chapter 4 is the context chapter and focuses on building a basis for chapter 5. First the context needs to be researched and a basic understanding of the current position in the transition is needed. Subsequently the chapter continues with a discussion of the components of the sociotechnical system regarding the physical system, tasks and market structure and roles of the relevant actors. Chapter 5, which can be seen as the more empirical analysis focused part, focuses on analysing the data collected on the factors, barriers and opportunities. The master's thesis concludes with the conclusion and reflection in Chapter 6.

1.2 Societal and scientific relevance of the proposed research

1.2.1 Societal relevance

As has become clear from the problem statement, there is a practical problem surrounding the energy transition and in particular the mobility transition related to this. If a transition towards

Fuel Cell Electric Vehicles is going to happen, then a large amount of related infrastructure would be needed to support this (Brey, Carazo & Brey, 2018). This master's thesis research can contribute to a better transition of this infrastructure when its aims are reached. More specifically these are the knowledge gathering, analysis and suggestions for solutions described in the research aim, that this research aims to generate. It is in the public interest to have sufficient infrastructure for FCEVs. Furthermore, from the larger picture of climate change, research focussed on alternatives to fossil fuels can support the reduction of greenhouse gas emissions and therefore reduce global warming and limit climate change. Mobility is a major contributor in the current greenhouse gas emissions (Apostolou & Xydis, 2019), thus it deserves considerable attention. In 2015 24% of the global greenhouse gas emissions were contributed by the transport sector. Since 1990 total EU greenhouse gas emissions have decreased slightly while road transportation has had an increasing share in this: 12% in 1990 to 24% in 2015 (Apostolou & Xydis, 2019). Therefore, large gains could possibly be made in the transportation sector when transitioning to sustainable mobility. The possible contribution of this thesis to these large problems makes it relevant to the society. As explained in the section on research aims, the research focuses on the implementation of the hydrogen infrastructure and not on the viability of hydrogen (mobility) compared to other fuels. The implementation of infrastructure is already very relevant on its own. The limits of the scope need to be protected and therefore the question of viability is not explored in this research.

1.2.2 Scientific relevance

An important part of the framing of this research is the scientific relevance. This means placing the research in a so-called knowledge gap which is a lack of scientific knowledge on a certain subject. The knowledge gap in which the subject of this master's thesis is situated comes from a general lack of scientific research on the subject as well as a more specific lack of scientific research focussed on the Netherlands. Some literature that is focused on the Netherlands such as Smit, Weeda and de Groot (2007) is relatively old, meaning their results might not be up to date. This master's thesis can contribute to providing more recent results aimed directly at the Netherlands. There is also little literature on the spatial effects of hydrogen filling stations, this is limited mostly to citizens opinions (Huijts & van Wee, 2015) or on safety distances (Matthijsen & Kooi, 2007). The sociotechnical systems approach has been used in several different contexts. Using this theory might give new insights that can improve the transition and therefore adds to the scientific relevance of this master's thesis. It has become clear that there are several studies that border the subject of transition and hydrogen infrastructure implementation. However, none cover the exact subject presented here. This lack of research aimed at the Netherlands and on this subject therefore presents a knowledge gap that this thesis can cover. The research will provide insights and might show that this approach can be used to research similar transitions and can therefore generate opportunities for follow up research.

2 Theoretical framework

In this chapter the underlying theories are explored, which are used for the analysis of the research problem. There are multiple relevant theories for this research. The main focus of this chapter will be on theory related to analysing the introduction of new infrastructure. These are strategic niche management, sociotechnical systems and the diffusion of innovation. After this, a number of factors that could influence filling station implementation are identified and explored. Lastly a conceptual model will be presented and explained in which the theory is visualised.

2.1 Strategic niche management

Sustainable innovation can take place through the introduction of new technology, for example in the form of a new type of infrastructure. This regime change can be difficult to create and therefore this has been studied. Strategic niche management, as described by Schot and Geels (2008) is a theory that focuses on how to introduce new technology. They see creating a niche as an essential step towards sustainable development. A niche is a protected space where the new technology can be developed and experimented with. Multiple niches can work as building blocks and create societal change which is needed for sustainable development.

By slowly exposing the technological niches to the market, old technology can be replaced by new technology. For this research that would mean contemporary gas stations being replaced by hydrogen filling stations. This change is also referred to as a regime shift. The figure 2.1 below visualises how this shift happens. The technological niches in the first circle can be seen as the first types of hydrogen filling stations. In the second circle they expand into market niches while another technological niche grows. In the third circle they grow further and replace or become the new regime. In the meantime, new niches can grow and disappear (Schot & Geels, 2008).

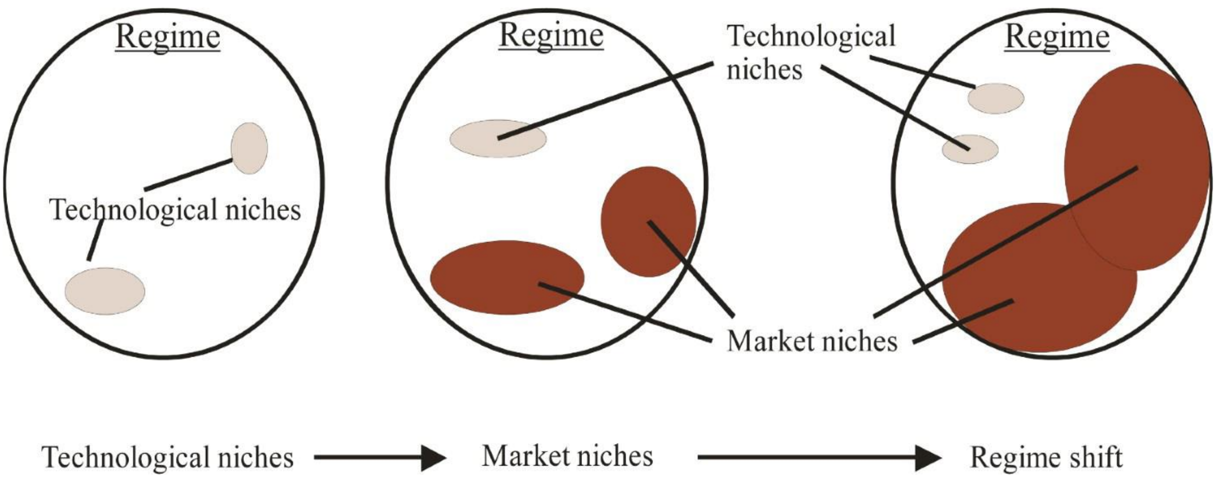

Figure 2.1: Regime shift visualised (Schot & Geels, 2008).

It is important to identify what makes a niche development successful or unsuccessful. According to Schot and Geels (2008) there are three main factors that contribute to the successfulness, (1) articulation of expectations and visions, (2) building of social networks, (3) learning processes at multiple dimensions. It is also argued that minimal involvement of outsiders or of regime actors often cause the failure of the niche, or in other words the niche not resulting in a regime change. From these three factors the building of social networks is interesting for this research. Schot and Geels (2008) argue that this factor also influenced the learning processes and therefore is of crucial importance.

Another important remark made by Schot and Geels (2008) is that niches cannot create the social change on their own. They need to be linked to ongoing external processes for example and there is a multi-level perspective which shows that this interaction at different levels is needed. This multi-level perspective is shown in figure 2.2 below.

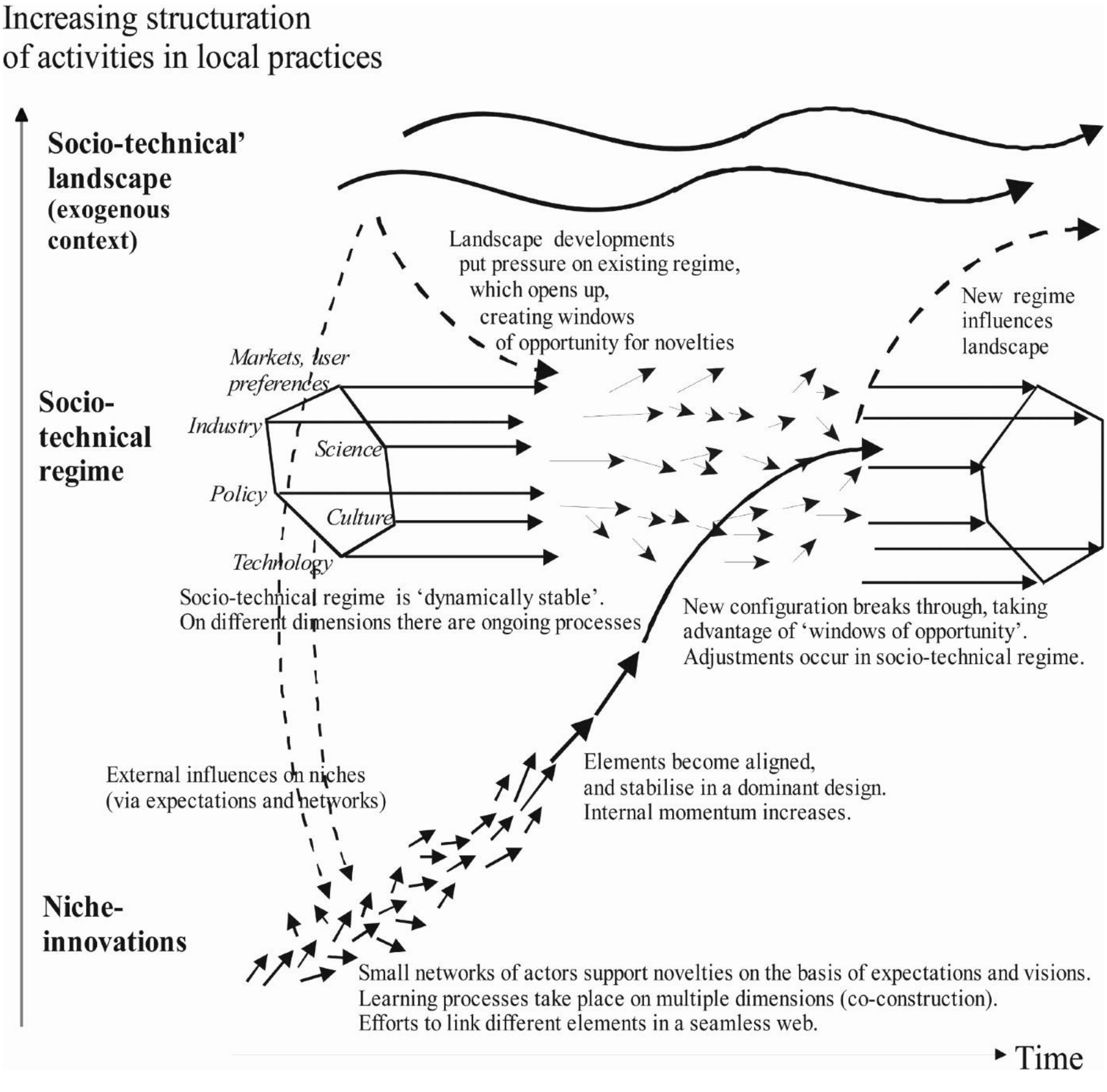

Figure 2.2: The multi-level perspective on regime change (Schot & Geels, 2008).

As shown in the figure, sociotechnical systems consist of niche-innovations, the sociotechnical regime and the sociotechnical landscape. It shows the regime change discussed before and it shows that from a small niche a regime change can occur which in turn will influence the landscape. This takes place through the alignment of several niches which in turn joins the regime. In the regime the configuration of the six components that make up the regime is changed. The figure shows the aforementioned influence from the regime on the landscape and from both the landscape and regime on the niche. The landscape can be seen as the context that changes because of the new technology. The importance of small networks of actors in the niche is also shown. These are the people that align the elements and create the momentum for the regime change (Schot & Geels, 2008). For this research, the niche would be a certain type of hydrogen filling stations, one type becomes the regime and this could then become a part of the mobility fuel and filling infrastructure.

2.1.1 Reflecting on strategic niche management

A research that was more pointed towards infrastructure is that of Turnheim and Geels (2019). They researched innovation in infrastructure for sustainability transitions also referring to strategic niche management. According to these authors strategic niche management (SNM) is still relevant but they suggest three changes or possible additions that can be made to the SNM system:

- Incumbent actors: These are actors from neighbouring regimes that are not orientated towards the niche or upcoming regime. When these actors are influenced then they might reorient themselves towards the niche and thus start working in a positive way for the niche. This is useful to convince locked-in actors (who are unable to change regime as a result of political or economic reasons for example) to join through countervailing power (Turnheim & Geels, 2019). The concept of incumbent actors might be useful when looking at hydrogen filling stations and ways to increase the number of them in the Netherlands.
- Guided search paths: Strong guidance and early direction setting or vision making can be effective in stimulating radical innovation. Especially for infrastructure and climate change when a fast change is necessary. There, instead of small short term steps, a more strategic approach is successful (Turnheim & Geels, 2019). This can arguably be seen as using a more top-down approach instead of a bottom-up approach that is usually preferred.
- Landmark projects: Infrastructure projects such as the tramway project example used by Turnheim and Geels (2019) can have large side effects when they are integrated projects. The tramway project example influenced the quality of life of citizens and reduced emissions through changing the modal split. When a single development has this many positive side effects, it can be seen as a landmark project. These landmark projects can essentially cause a faster regime change and might arguably be seen as a catalyst for further development (Turnheim & Geels, 2019). This could prove particularly useful for the implementation of hydrogen filling stations.

In addition to the three factors introduced above, another important factor is discussed that in its turn influences elements of the factors discussed before. Resource commitments in the form of substantial and stable funding are very important. In the case that is discussed by Turnheim and Geels, the gathering of adequate funding was aided by the guided search path and it helped to convince incumbent actors (Turnheim & Geels, 2019). This shows that the importance of funding cannot be forgotten when looking at strategic niche management, especially because of its interrelatedness to other factors. For hydrogen filling stations this is best shown in the ability to create a business case.

2.1.2 Sustainability transitions

A recurring pattern in Turnheim and Geels' (2019) additions to strategic niche management are the different needs that sustainability transitions have compared to normal transitions. They argue that a system reconfiguration is needed instead of incremental or fragmented change for sustainability transitions. Another difference is the fact that sustainability transitions need a faster change than normal transitions, there is a lack of time in the form of climate change (Turnheim & Geels, 2019). This could mean a more strategic and top-down approach to change is preferred over the bottom-up change normally used for transitions. This is interesting for the hydrogen mobility transition because perhaps a more top down-approach could be more successful than the currently used approach.

2.2 Sociotechnical systems

The transitions discussed in the section above can also be looked at from the perspective of transition management and can be characterized as a sociotechnical system (from now on STS). An STS shows the relationship between technology and human behaviour. The sociotechnical system perspective is according to Geels (2004) particularly useful for analysing shifts from one sociotechnical system to a new sociotechnical system. He states that both the production and user side are important parts of a technological system and thus suggests a sociotechnical system. His definition of the STS is as follows: “the linkages between elements necessary to fulfil societal functions (e.g. transport, communication, nutrition)” (Geels, 2004, p.900). In order to achieve a sociotechnical transport system, production, diffusion and use of technology are needed. The STS as viewed by Geels (2004) is shown in figure 2.3 below. The systems would not work without actors that make them work. These actors are once again part of social groups where actors with the same roles, responsibilities or other characteristics come together. An overview of these actors is given in the figure 2.3 below. The author states that there are multiple levels of interaction within the groups but also between different groups through a network (Geels, 2004). These networks will be discussed in more detail in the next section on actor-network theory. The transitions described above are similar to what is also happening with the shift from the current mobility system to a hydrogen mobility system.

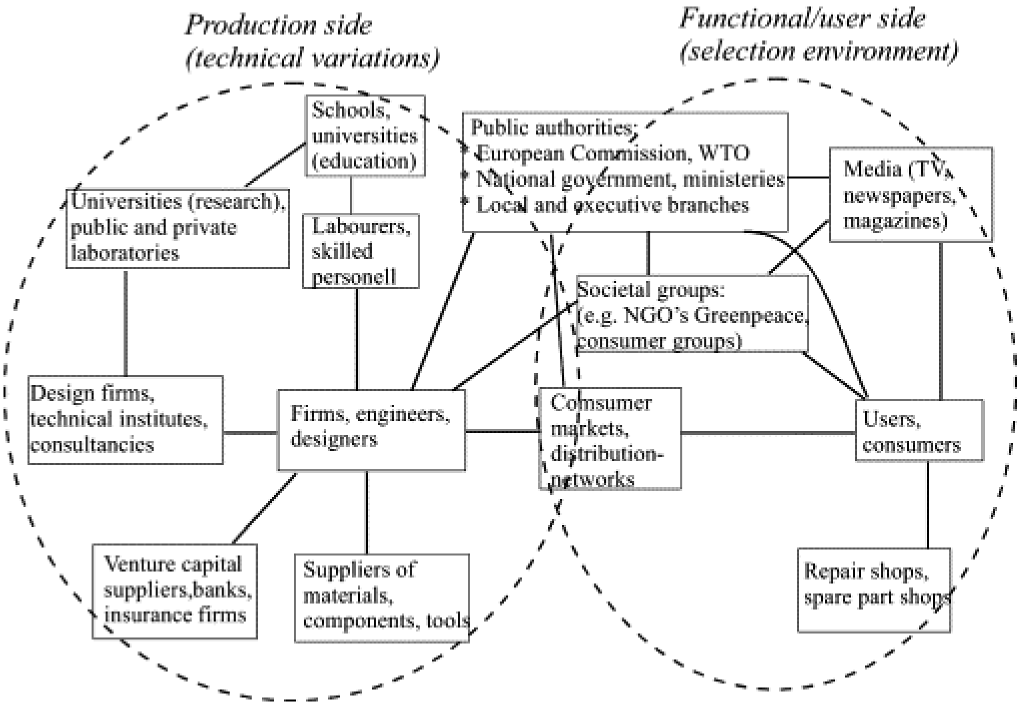

Figure 2.3: Actors in sociotechnical systems (Geels, 2004).

In order to solve complex issues, the combination of the technical system and the social system is important. Oosthuizen and Pretorius (2016) use the example of new technology in an organization. Just introducing a new technology is not automatically going to work because human beings are also involved. Human beings are complex and sometimes unpredictable and engage in complex relationships with other human beings. As a result of this, the interplay between the social and the technical system is essential for new technology to work (Oosthuizen & Pretorius, 2016). Figure 2.4 below shows this interplay and the different components that can be distinguished in the social and the technical systems. Furthermore, it also shows that there can be a complex environment surrounding the system itself, and this environment can influence the four components (Oosthuizen & Pretorius, 2016). This sociotechnical system matrix can be used for analysis of practical situations. All four parts need to be aligned so that the system will be aligned (Bider & Klyukina, 2018). From this you could argue that if one of the components is lacking, the whole system might not function as it is supposed to.

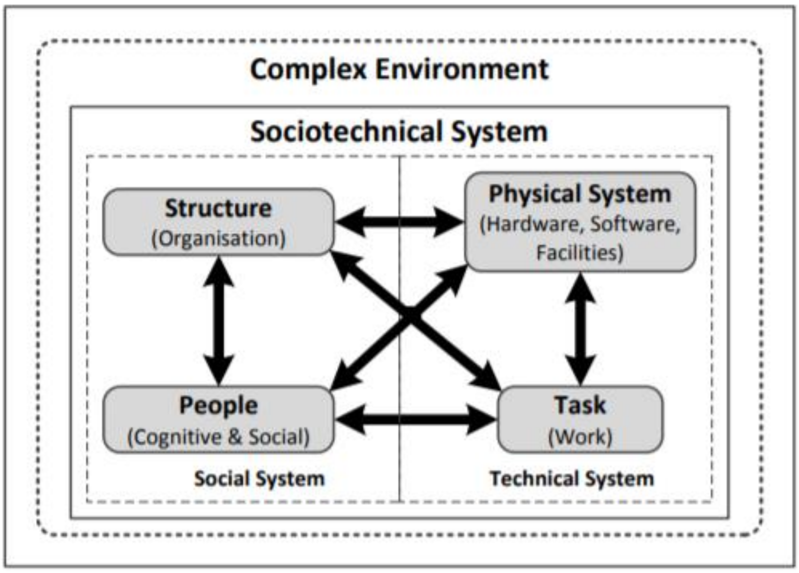

Figure 2.4: The interplay between social and technical systems and the four components (Oosthuizen & Pretorius, 2016).

In figure 2.4 the four components of sociotechnical systems are visible: structure, people, physical systems and tasks. These four components are important to this research because they will form the main thread. The components can be interpreted differently in a different context and will therefore be explained and operationalised in more detail.

2.2.1 Structure

Structure can contain different meanings depending on its context. This research uses the context of hydrogen filling station implementation and therefore structure will contain an applied meaning. For this research, the structure accounts for the specific organisation of the implementation of the filling stations. In other words, structure encompasses the actors engaged in implementing hydrogen filling stations and their relations to each other. This organisation is what provides the backbone for the implementation. More concretely this means the interplay of the actors and what they do or what roles they play. The actors are connected to each other, for example with supply and demand relations. Defining and analysing these relations will therefore give insight into what role the structure plays in the implementation.

2.2.2 People

For this research the people component is operationalised as the end-users of the hydrogen filling stations. They are the people who will own hydrogen vehicles and therefore demand things from these filling stations. They are explicitly not the actors that are engaged with the implementation of the hydrogen filling stations, who are part of the structure component. The people that are the end-users will not be addressed in this research because this is not in the scope of the research. The focus is placed on the implementation of hydrogen filling stations and the related transition, thus not on the end users themselves. Even though the lock-in is arguably partially caused by the end-user side, they will not be researched themselves. The other three components provide a large and complicated enough subject of study. The end-users can be a subject of study for follow-up research.

2.2.3 Physical System

The physical system component is operationalised as the technological, spatial and thus physical aspects of a filling station. There might be limitations coming from the technological or physical side of the system that cause barriers. These barriers will have spatial effects and result in implications for the spatial context. For example, choices for storage of hydrogen might have affect the safety regulations which in turn cause the external safety distances to change. This means that a larger area around the filling station must be left open or that the filling station cannot be placed near an apartment building for example. The interrelatedness of the physical system is shown because it can influence the tasks by providing or not providing the ability to perform certain tasks because of physical limitations.

2.2.4 Task

The task component is operationalised as the capabilities of the sociotechnical system, or in other words, things that the technology is capable of doing. A system must be able to perform certain tasks and that might be where the problem lies. If it is not able to perform these tasks then it might be limited by other components such as the physical system. The technological components or other physical problems can limit the functioning of the sociotechnical system. The analysis in this research will pay attention to these possible problems.

Two approaches

Within sociotechnical systems theory there are multiple approaches. Two that are identified by Auvinen and Tuominen (2014) are the Large Technical Systems (LTS) approach and Social Construction of Technology (SCOT) approach. They use these approaches mainly to show and identify the following:

“.. system-level changes, technological stabilisation being part of it, can be understood only if the technological aspects are seen as being interrelated with a wide range of non-technological factors.” (Auvinen & Tuominen, 2014, p. 345).

The non-technological factors the authors mention are partially what can be identified as the social part of social-technical systems. These approaches are particularly useful for analysing the past. Auvinen and Tuominen argue that we need foresight to create good transitions (Auvinen & Tuominen, 2014). This approach shows the importance of visions and strategic plans. No choice is made between these two approaches in this research.

2.3 Diffusion of innovation

For a transition it is important to know the current position in the process of innovation. For this purpose, the diffusion of innovation theory and the accompanying S-curve can be used. Matinaro and Liu (2015) discuss this theory originally composed by Rogers. There are four important factors that influence the adoption of a new idea: the innovation itself, communication channels(media), a social system and time. Five categories of adopters are identified, namely: innovators (2,5%), early adopters (13,5%), early majority (34%), late majority (34%) and laggards (16%). The innovativeness of the adopter is used as a criterion to define in which category they are. In order for an innovation to self-sustain it must be widely adopted. There is a point of critical mass within the rate of adoption which is also the take off point as can be seen in figure 2.5 (Matinaro & Liu, 2015). High-tech innovation adoption has some additional implications. In general, the adoption speed is slower for this type of innovation. Sometimes an adoption gap may occur exactly at the take off point, between the early adopters and early majority. This is particularly the case with high-tech innovation (Moore, 1999 in Matinaro & Liu, 2015). When hydrogen mobility is perceived as high-tech, there might be a similar adoption gap in this transition.

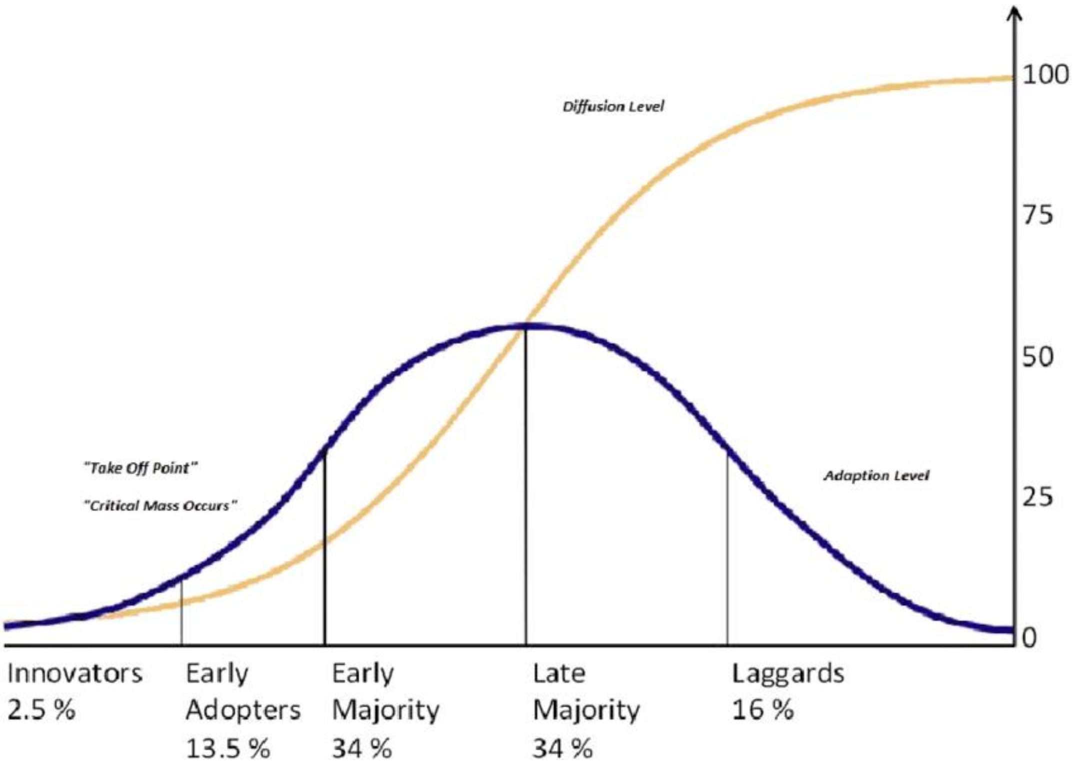

Figure 2.5: Rogers S curve of innovation (Adapted by Matinaro & Liu, 2015, from Rogers, 1995, p.262).

The percentage of adopters which is also shown in figure 2.5 can be compared to the time that has passed, as is shown in figure 2.6. This is also similar to an S-curve but it flattens at the end and therefore shows that the laggards (latest adopters) take longer to adopt the innovation. However, there are some very important remarks made by Rogers. The curve should not be expected to be exactly the same in every situation. For example, the adaption velocity may differ when the social systems for example are different in another situation. The velocity is also dependent on how useful individuals think the innovation is. When it is perceived more useful the adoption velocity will be higher (Rogers, 1995, in Matinaro & Liu, 2015). In chapter 4 the position in the S curve of the hydrogen transition will be analysed.

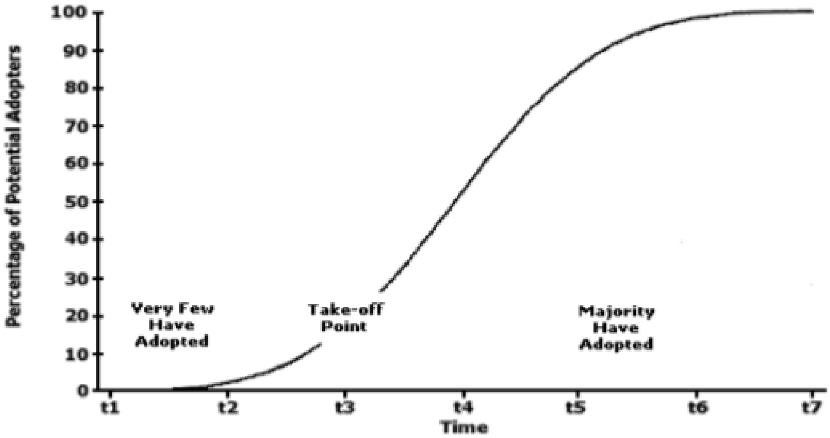

Figure 2.6: The diffusion curve (Adapted by Matinaro & Liu, 2015, from Rogers, 1995, p.262).

2.4 Actors, sectors and spheres

As discussed above, the building of social networks is very important for the creation of regime change. In this research the actor landscape and market structure will be explored in order to address the structure component in the conceptual model. Therefore, it is relevant to explore the literature regarding this subject. The aim is to show how the different interests of actors can be related to each other or characterized and how these interests stimulate or counteract spatial developments.

2.4.1 Actor characterization

Mitchell, Agle and Wood (1997) have defined a way to characterize actors (stakeholders) with three factors: power, legitimacy and urgency. They state that each actor should have one or more of these relationship attributes. This is valuable for characterizing the actors that are involved with filling station implementation. Though it must be noted that the three factors are socially constructed and therefore not objective measures.

Power is defined as carrying out your own will despite resistance and therefore the ability to realise the outcomes they desire. There are three different types of power identified that also influence the extent to which an actor has power. These are coercive, utilitarian and normative, which means that the access an actor has to coercive, utilitarian, or normative means also determines their level of power. Because the access to these means can change, the level of power an actor possesses can change as well (Mitchell, Agle & Wood, 1997).

Legitimacy determines if an actor is viewed as legitimate or illegitimate. Legitimacy is defined as: “a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions” (Suchman, 1995, p. 574 in Mitchell, Agle & Wood, 1997). Power and legitimacy do exert influence on one another. When a powerful actor is not legitimate it will likely lose power eventually. Furthermore, an actor that is viewed as legitimate in society still needs power to enforce this legitimacy or perception that its claim is urgent (Mitchell, Agle & Wood, 1997). Arguably, state actors are legitimate in the Netherlands because they have been democratically chosen and are generally not contested.

This brings the next factor, urgency into play. Something is defined to be urgent when it is seen as a pressing matter or one that calls for immediate attention. Two conditions have to be met for urgency to exist. This is a time-sensitive nature and it has to be important or critical to the actor (Mitchell, Agle & Wood, 1997). The hydrogen transition and climate change are both of a time-sensitive nature, so there is a degree of urgency. Whether it is important or critical to the actors, remains to be seen. Chapter 5 will go into detail and will explore to what extent the actors in filling station implementation can be characterized with these three factors.

2.4.2 Sectors and spheres

In transitions and in spatial projects, the balance of power between actors can shift. It is important to find out who exerts power on who and who is empowered by who. Avelino and Wittmayer (2016) have developed a framework for specifying these relations between actors. They argue that transitions take place in the institutional triangle between state market and civil society (called community by them) making them have a multi-actor nature. The authors have distinguished four sectors: state, market, community and non-profit or the 'third sector'. They have also distinguished three levels of aggregation: sectors (the sectors as described before), organizational actors (e.g. municipality, university, multinational, club etc.), and individual actors (e.g. politician, consumer, activist, resident etc.). These can all be filled into the sectors within the multi-actor perspective pyramid, as shown in figure 2.7 below. The aggregation of individual actors shows that actors have different roles they take upon them. This can be multiple roles at once. Similarly, organizations can also participate in different sectors at once (Avelino & Wittmayer, 2016). The MPA can be used to characterize the different actors involved in the implementation of hydrogen filling stations and the related transition.

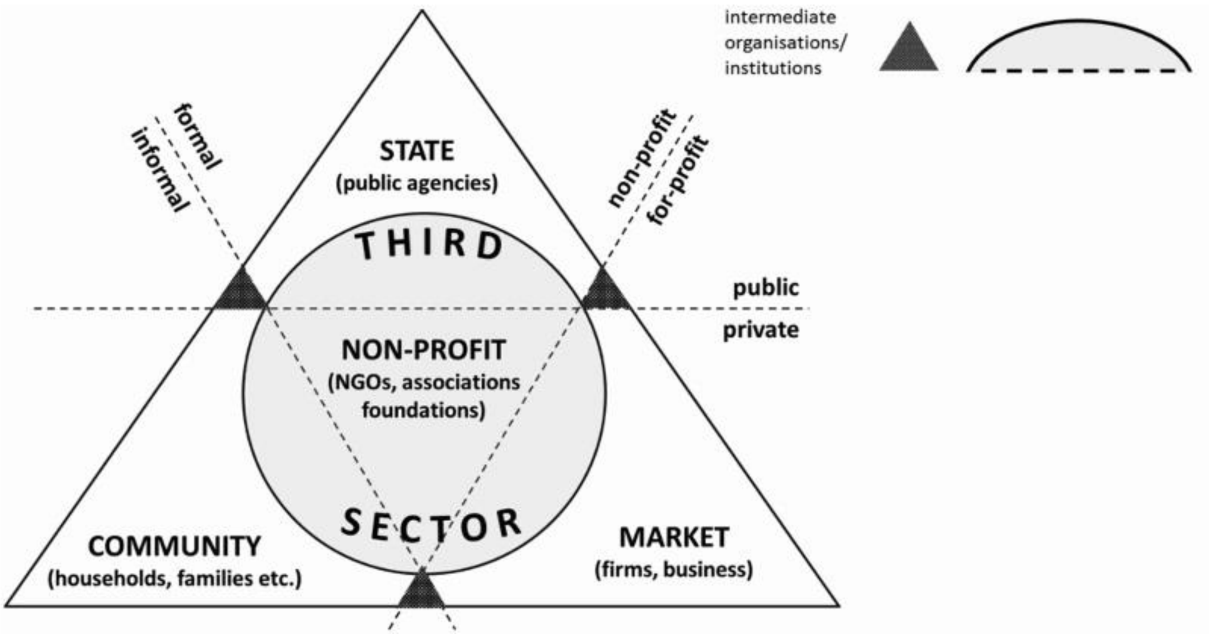

Figure 2.7: The multi-actor perspective pyramid (Avelino & Wittmayer, 2016).

To go into further detail on this subject the work of Steurer (2013) can be used. He uses a similar typology to the sectors like Avelino and Wittmayer but uses different terms and spheres instead of sectors (triangles). Every sphere has its own types of regulation or co-regulation when multiple spheres come together (Steurer, 2013). These can be useful when looking at the roles of different actors in hydrogen filling station implementation. The spheres and types of regulation are given in figure 2.8, below.

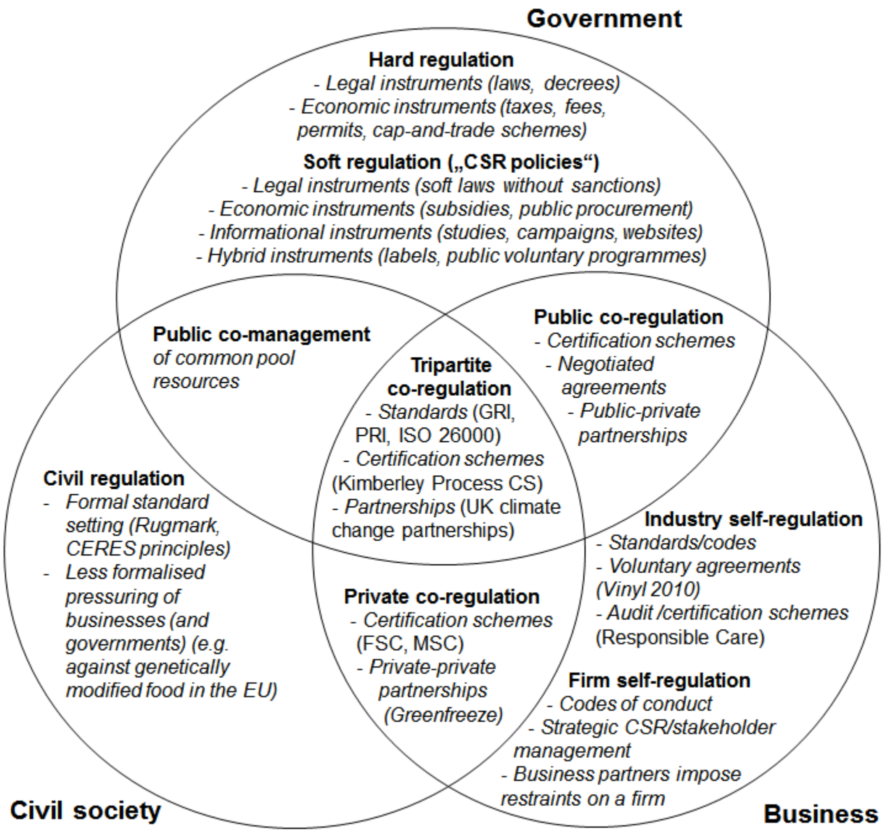

Figure 2.8: Types of regulation and co-regulation with the according actor spheres (Steurer, 2013).

2.5 Factors and possible barriers

It is possible to define several factors that have to be taken into account for the implementation of hydrogen filling station infrastructure. Factors that can influence the hydrogen transition and filling stations are an economic or business-case, safety, location and public opinion. These factors have been found by searching the literature by this is not meant to be an all-embracing list of factors. The following paragraphs explain these factors in further detail.

2.5.1 Economic

The following article by Offer, Howey, Contestabile, Clague and Brandon (2010) shows the economic factor by comparing the costs (among other things) of several alternatives to fossil fuel cars. This source shows the differences in costs between battery electric vehicles, hydrogen electric vehicles and hydrogen fuel cell plug-in hybrid vehicles. It concludes that hydrogen fuel cell plug-in hybrid vehicles are the best, cost effectiveness wise (Offer, Howey, Contestabile, Clague & Brandon, 2010). This is most likely related to the ‘fuel’ costs which are in turn related to high infrastructure costs.

The economic factor is explored further by comparing infrastructure for electric and hydrogen electric vehicles. Brey, Carazo and Brey (2018) approach hydrogen infrastructure from a dual perspective: investor and end-user. Both an investor that invests in infrastructure is needed and an end-user who pays for the hydrogen. Their study contains a case-study on a

Spanish city and shows the gap between gasoline and hydrogen fuel prices in Spain. They also address the choice for a system, which is relevant to this master's thesis (Brey, Carazo & Brey, 2018). These fuel prices might have an influence on the viability of a hydrogen filling station.

2.5.2 Safety

In the article by Lipman, Elke and Lidicker (2018) safety was defined as an important factor and barrier. Their research was focused on the perception of FCEV users and shows their opinion before and after using these vehicles. Some users had concerns about the safety of hydrogen as a fuel and the vehicle while others had concerns about the safety of fuelling their vehicle. In the end it turned out that opinions after using were much more positive than before and were largely positive. About 54% of FCEV users felt that they were safer than gasoline vehicles while 98% felt they were at least as safe as gasoline vehicles. Users adapted quickly to the differences and as it turned out 94% of users felt safe when fuelling their hydrogen car (Lipman, Elke & Lidicker, 2018).

The safety of the hydrogen filling stations is very important when keeping spatial effects and the effects of places on people in mind. To ensure safety, rules have been set up for the implementation of hydrogen filling stations and for permits. Backhaus and Bunzeck (2010) describe in their article how this process takes place in the Netherlands. First of all, Quantitative Risk Assessments (QRA) have to be made for hydrogen filling stations but there is no specific guideline on how to make a QRA for these hydrogen filling stations. There is only a generic prescribed approach on how to make a QRA. This QRA is needed for the environmental permit that is in turn needed in order to create a hydrogen filling station. The other permits are the building permit and operating permit, all three are provided by the municipality. The purpose of the permitting process is limiting the risk of the hydrogen filling station to people and the environment. More effective and efficient permits can be made when safety requirements and permit processes are harmonized. There is a specific guideline for permitting hydrogen filling stations in NPR 8099:2010 and its successor PGS 35:2015 (Backhaus & Bunzeck, 2010). The NPR and PGS are abbreviations for Nederlandse Praktijk Richtlijn (Dutch Practical Guideline) and Publicatiereeks Gevaarlijke Stoffen (Publication Hazardous Substances) made by the Dutch Standardisation Institute. They are documents that contain all the rules on hydrogen and are there to ensure that for example permits are given out by the same rules.

Matthijsen and Kooi (2006) wrote about the safety distances for hydrogen filling stations. The RIVM has researched the external effects created by failure and came to the same external safety distances as are needed for gasoline, figure 2.9. The research was done for high and low pressure (350 or 700 bar) and three hypothetical sizes of filling stations determined by the number of cars that are fuelled on a day. This means that hydrogen filling stations (maximum safety distance of 15 meters) can be placed at normal gas stations. Only LPG has a much greater distance, of 45 up to 110 meters for the filling point and is thus deemed more dangerous than hydrogen. The capacity of the filling station does not have a large effect on the safety distance. For the dispenser however the safety distance doubles from 5 for a small station to 11 meters for a large station, according to the authors this is due to the doubling of the number of dispensers (Matthijsen & Kooi, 2006).

Station	IR 10^{-6} contour radius (m)		
	Buffer	Pipeline	Dispenser
Small	10	4.5	5.0
Medium	11	4.5	6.5
Medium (700 bar)	15	5.5	8.5
Large	13.5	4.5	11

Figure 2.9: Safety distances based on the risk contour radius (Matthijsen & Kooi, 2006).

2.5.3 Location

The location is discussed by Wang and Lin (2009). They discuss several models for deciding on which locations should have a hydrogen filling station. In basis the vehicle range is a deciding factor for determining the location. Vehicles need to have enough range to reach the stations and therefore the spread should not be too large. The authors argue for placing sufficient filling stations along highways in order to facilitate for long range travel, at least in the early stages. These are necessary to make sure that consumers have enough confidence in this type of transport (Wang & Lin, 2009).

When discussing citizens opinion on hydrogen filling stations, the study conducted by Huijts, de Vries and Molin (2019) is very relevant. It shows that after implementation of a hydrogen fuel station the people living close by to it change their opinion. They view hydrogen more positively after it has been implemented and the advantages start to weigh more than the disadvantages to them (Huijts, de Vries & Molin, 2019). This shows that opinions might change after implementation and that governments should work on informing the citizens correctly.

2.5.4 Public opinion

There is extensive literature available on public opinion, public perception or public acceptance of hydrogen infrastructure and Fuel Cell Electric Vehicles. An example of this is Itaoka, Saito and Sasaki (2017). They specifically researched the public awareness, knowledge, perception and acceptance regarding hydrogen, hydrogen infrastructure and fuel cell vehicles in Japan. They compared their results to surveys done six and seven years prior. They found that awareness had increased but people had become more cautious about the risks and benefits that come with hydrogen mobility and its infrastructure (Itaoka, Saito & Sasaki, 2017). This caution shows that people might have concerns regarding a new innovation like hydrogen that should be taken into account.

2.6 Conceptual model

The conceptual model, figure 2.10, contains elements from several of the theories introduced above. It follows the hydrogen mobility transition from left to right, starting from a niche going to a regime. The arrow in between the niche and regime represents the transition. The conceptual model firstly contains elements from the STS model used by Oosthuizen and Pretorius (2016) as can be seen in figure 2.4 earlier in this chapter. The components were operationalized for this context and the explanation is added to each component. The people component was left out for the reason explained in chapter 2.2. These structure, physical system and task influence the transition which in turn influences if the niche becomes a regime. All three of them are discussed in chapter 4. The components of the STS influence each other as is shown with the arrows between them. These arrows are where the barriers and opportunities can be found. When the barriers decrease how well the STS works, the effect on the transition is also influenced. The transition is also influenced by the factors from chapter 2.5 which are shown at the left side of the figure with an arrow pointing to the right towards the STS. These factors influence the sociotechnical system and therefore have an indirect effect on the transition. However, there is also a limited direct effect of these factors on the transition which is visualized with the dotted arrow going from the factors to the transition. The size of the three normal arrows shows how important these effects are for this research.

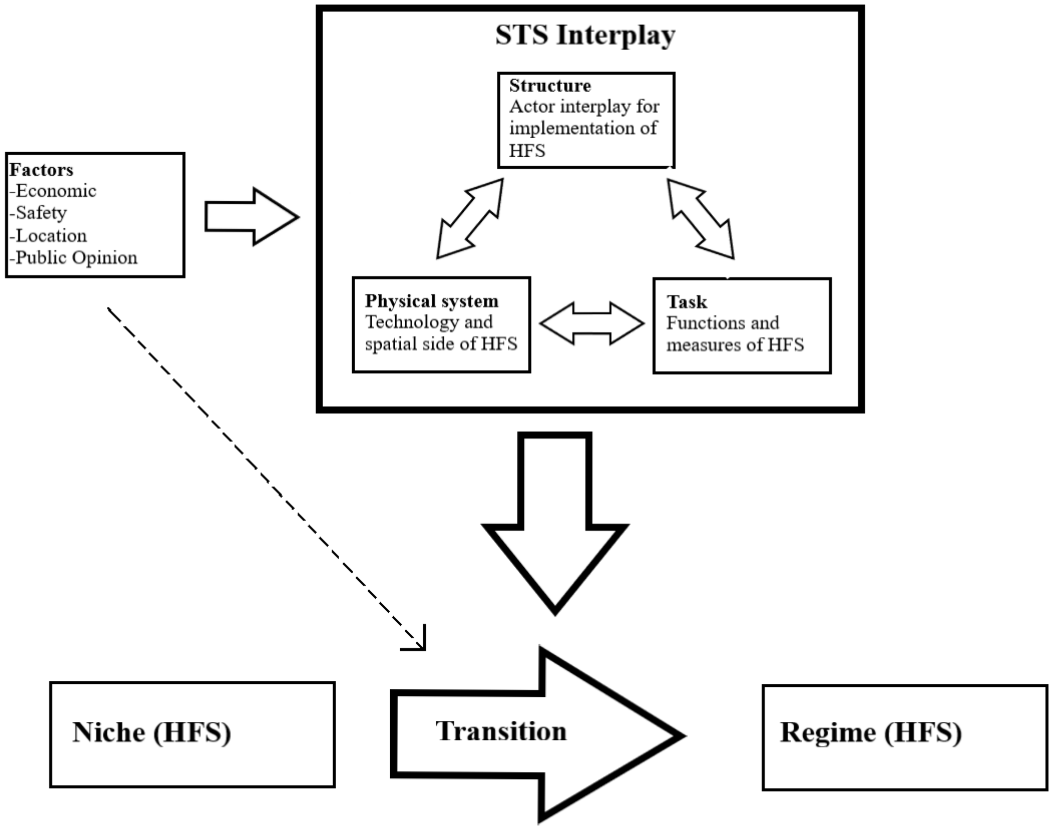

Figure 2.10: The conceptual model for this master’s thesis.

3 Methods

3.1 Research strategy

This section on research strategy starts off by using research philosophy in order to formulate a research approach. There are multiple possible subdivisions that can be made by using research philosophical literature. First of all, a choice between an empirical analytical and an empirical interpretative approach had to be made (Van Thiel, 2014). This is also where the subdivision between deductive and inductive research becomes apparent. The empirical analytical approach is mostly deductive research while the interpretative approach is mostly inductive research. Because this research has an exploratory and descriptive nature, the inductive approach is the most logical. There is no large body of knowledge needed from which hypotheses are to be deducted (Van Thiel, 2014). Therefore, for this research an empirical interpretative approach was chosen.

Several typical characteristics of inductive research can be identified. Firstly, it is based on identification with a unique subject of study. Secondly, the meaning and relations of the subjects of study are often explored. Lastly the aims of the research are often description and understanding of the subject (Van Thiel, 2014). One of the advantages of the inductive approach is the ability for the researcher to engage in the research itself and ask further questions on topics that arise during interviews for example. However, it must be noted that this is to a certain extent also possible with a deductive approach. Therefore, a more in-depth analysis of the data could be possible, and the relations can be defined. These are advantages that are very useful for this master's thesis. There are also downsides to this approach, some of which will be discussed at the validity and reliability section. Firstly, it is very time consuming to analyse large amounts of qualitative data and to transcribe interviews. Secondly, the inductive approach might be seen as more difficult than a deductive approach as a result of the generation of theory instead of the testing of theory (Van Thiel, 2014).

This master's thesis research consists of two phases namely a <u>context</u> phase and an <u>analysis</u> phase, which are clear in the way the chapters are composed. The first phase of the research focused on understanding the technology, tasks, actors' roles and market structure (the components of the sociotechnical system). The second phase focused on the analysis of the data on the factors, barriers and opportunities. In these two phases multiple different research methods were used. The next section will go into more detail on these methods. The use of multiple methods makes it difficult to define exactly which of the four main research strategies defined by Van Thiel (2014) were used. It can be supposed that a mix of the two best fitting strategies, case-study and desk research, were used.

3.2 Research philosophy

Research philosophy is important to discuss because it defines your approach and philosophical starting point for your research. For this research, the interpretative approach was used. The interpretative approach assumes that everyone has their own perspective or personal view of reality and thus knowledge is subjective and subject to interpretation (Van Thiel, 2014). The interpretative approach tries to answer questions that can be left unanswered when an empirical-analytical (quantitative) approach is used. The central aim of the empirical interpretative approach is understanding the social reality. According to this approach it is important to look through the eyes of your subject of study in order to understand this social reality. Researchers within the empirical interpretative approach look for ideographic knowledge: knowledge that describes the own or uniqueness. This is different from the knowledge of laws (or theories) that is strived for in quantitative research. This uniqueness is reflected in that interpretative research focuses on looking for patterns or differences in the subject of study, for example behaviour. Interpretative approach tries to combine the perspective of the researched with the researcher. The research subjects have their own views of reality which are compared with that of the researcher through analysis (Scheepers, Tobi & Boeije, 2016, pp. 75-78). For this research this means that the interviewees perspectives are analysed by the researcher by comparing this with his own perspective.

When diving deeper into the research philosophy it is important to define the relevant paradigm by Guba and Lincoln (1994) for this research. The paradigm can be explained by looking at its ontology, epistemology and methodology. The ontology of a paradigm is how it answers the question if reality does exist. The epistemology is how it answers the question whether we as human beings can actually know reality and whether there is just one reality that is the same to each and every living person, reflecting on the objectivity of research. The methodology is the general approach to doing research (Van Thiel, 2014). The most suitable paradigm for this research is constructivism which is suitable for research aimed at understanding or reconstructing, like this master's thesis. Constructivism is based on a move from ontological realism to ontological relativism. This relativism is based on the assumption that local and person specific mentally constructed realities exist, but there is not one objective reality. The epistemology is called transactional or subjectivist by Guba and Lincoln. This means that the researcher and research subjects are assumed to be interactively linked. The interactions between these two results in the creation of the findings. The methodology is called hermeneutical and dialectical. Social constructs can be studied by a researcher only by interacting with the research subject. Social constructions are interpreted using hermeneutical techniques and are compared and contrasted using dialectical techniques (Guba & Lincoln, 1994). The methods that are used will be further discussed in the next section.

3.3 Research methods, data collection and data analysis

This section describes the choice for research methods. Qualitative methods are best suited for this research because of the inductive nature of this research and the ability to gather in depth knowledge. Because some discussion remains over the usage of the term qualitative methods this has to be defined briefly. It is argued by Van Thiel (2014) there is no such thing as qualitative methods, only qualitative data. This has been taken into consideration, however because other sources commonly do refer to it as qualitative methods it was chosen to still use the term qualitative methods. Both the methods for data collection and data analysis will be discussed in this section.

This master's thesis research has taken place in two phases. The first phase started with a literature review in the form of content analysis which was complemented by the expert interviews. The second phase focused mainly on the expert interviews with several relevant actors in the field of hydrogen filling stations or related fields. The experts have been selected by making several categories of relevant actors. These are actors involved with the production of technology for the filling stations, actors involved with the implementation or planning of filling stations, actors from the three government layers and general hydrogen experts. When the right person for a certain group could not be found or was not available for an interview then a suitable replacement was sought. For example, for the municipality layer of government no actor was found but Rutger Beekman was interviewed about this because he had relevant information about the role of a municipality. In total nine interviews were held and a list of the interviews can be found in appendix B.

3.4 Methods for data collection

In order to acquire the necessary data several methods were used, as discussed above. The first method that was used is content analysis. Literature, policy documents and other information that was relevant to this research was collected on the internet and analysed. This content analysis also helped finding the experts that were needed for the second method.
The second, and main method for data collection was the use of expert interviews. Initially the goal was to hold in-person one on one interviews. However, because of the corona crisis this had become impossible and digital interviews were necessary. This resulted in the use of multiple different types of video or voice conferencing software. To the respondents Skype was proposed as the preferred software, but the final choice was generally based on the respondent's preference. The software used were Skype, Teams, and normal telephone conversation. Because of the uncertainty during this corona crisis period a back-up method was found in epistolary interviews, which is a written conversation type method (Lupton, 2020). In the end it was not necessary to use this method, but it was good to have a back-up plan.

In order to find the interview subjects purposive sampling was used. Based on theoretical grounds, the researcher selected different types of actors (Van Thiel, 2014). These actors were contacted by e-mail or telephone. After explaining the research and themes and goals of the interview an appointment for an interview was made. At the end of the interviews the interviewee was asked for possible interview candidates. This type of respondent acquisition is called the 'snowball' method. In total 17 possible respondents were contacted for this research. The eventual number of interviews to be performed was determined by finding the point of saturation, which was reached after nine interviews. No real new information was being gained at that point and actors from all the defined relevant actor groups had been interviewed (Scheepers, Tobi & Boeije, 2016, p.262).

The interviews were semi-structured, meaning a list of questions was used but there was freedom to deviate from this list. The order of the questions could change during the interview (Van Thiel, 2014). The lists of questions can be found in the appendix C. Initially one list of questions was made but later on in the research another was made aimed at government actors. Some questions that were deemed less relevant were left out while some new questions were added. An example of deviating from the question list is the interview with Beekman. Because shorter time available for the interview, only the most important and relevant questions were asked.

The interviews started with an introduction where the respondent was put at ease and the structure of the conversation was explained. The goal of this explanation was informing the respondent, making sure that the conversation would flow better as a result of this. The interviews ended with a concluding thank you and information on how the information would be used. A recording was made, for which permission was asked explicitly at the start of the interview, in order to enable analysis afterwards. Making a recording was preferred over taking notes during the interview because the interviewer can pay more attention to guiding the interview itself. Furthermore, when taking notes sometimes parts of the data can be lost because of the time pressure. Making a recording removes this time pressure and makes sure no data will be lost. The use of interviews over surveys was preferred because more detailed questions can be asked than with surveys and the ability to go further into detail by posing new questions is a very valuable addition (Van Thiel, 2014).

3.5 Data analysis

Each type of data collection needs to be analysed in a suitable manner. For the content analysis this means that the sources were gathered and discussed in order to contribute to the contextual chapter. This content analysis is not focused on defining a narrative, discourse or rhetoric used but instead aims to provide necessary background information. The content will be discussed in text but not analysed as Van Thiel (2014, pp. 108-110) describes.

The recorded interviews were first of all transcribed (written out). This took place by listening to the recording and writing down what was said. For this research, the words used by the interviewer to show that they were listening were left out from the transcript. Stutters, repeating words while thinking and 'uhm' words were also left out, to make the transcript more readable. For two interviews the transcript was sent to the interviewees in order for them to check if any sensitive information had to be left out. These were the interviews with the Province of Utrecht and Rijkswaterstaat. The transcripts were only used when permission from these interviewees was granted.

Subsequently the transcripts were labelled with a code in the software program 'MAXQDA 2020' for which a coding scheme or code book has been constructed. The codes that have been created can be found in the codebook which is attached in appendix D. The coding took place by first labelling the text by relating it to the code of one of the interview questions. Furthermore, when interesting findings were identified, a memo was added as a reminder. This provided the researcher with the ability to compare the data in a comprehensive manner. After this, the process of axial coding took place in which patterns were sought. For this research this meant going through the text once more and labelling the barriers and opportunities that could be identified. Eventually this resulted in attempting to generate new findings in chapter 5 (Van Thiel, 2014). In chapter 5 of this research a structure was made by focusing on the barriers and opportunities. It was decided not to make a complete SWOT analysis because the division in barriers and opportunities fits this subject better and is already substantive on its own and enough data was found on the barriers and opportunities. Furthermore, because of time constraints it was not possible. While analysing the interview data, links were sought with the literature from the theoretical framework such as the sociotechnical systems theory.

3.6 Reliability, validity and ethics of the research

Both the reliability and validity are important for research because they are ways to judge the quality of the research.

3.6.1 Reliability

Reliability is made up of two important factors which are accuracy and consistency. These two factors are used to make certain the results were not a coincidence but instead systematic and representative results. A high level of reliability will mean that no distortion has taken place when answering the research questions. In order to ensure a high reliability, data must be gathered as correctly and precisely as possible. For this research this meant that the formulation of the interview questions for example needed to be precise and correct. Consistency is mainly achieved by ensuring the repeatability of the research. This is difficult for a research in spatial planning because people change and can give different answers. This could however be achieved by documenting the methods used correctly and using reliable data collection methods (van Thiel, 2014). The precise formulation of the interview questions provided that the same question could be asked to the different actors which adds to the consistency.

Baarda et al. (2013) argue that guaranteeing reliability for a qualitative method is different, compared with quantitative methods. It is impossible to repeat an interview in exactly the same manner under the same circumstances and receive the exact same results. For quantitative methods for example a survey can achieve the same results. Baarda et al. (2013) combine both reliability and validity when giving examples of how to improve reliability and validity. It is important to use a methodology that is customary for the analysis. This has been done in this research by using interviews and coding. Furthermore, using computer software can also improve the reliability and validity. By using MAXQDA in this research this requirement has been met as well. Lastly, triangulation has also been aimed at achieving by trying to find multiple sources to support claims. Such as in chapter 5 where multiple interviews were used to support the argument that a barrier exists (Baarda et al., 2013).

3.6.2 Validity

A distinction can be made between internal and external validity. The former meaning if the research has measured what was aimed at and the latter meaning the amount to which a study can be generalized (van Thiel, 2014). An effect caused by the inductive approach was a lower generalizability and external validity. It was more difficult for the researcher not to intervene in the research. An interview needs interaction between the researcher and interviewee and is not necessarily completely standardized, while a survey is often standardized. This lower amount of standardization results in a lower generalizability and therefore external validity. The internal validity was difficult to assess because the research has not been completed yet. When assessing the data, the researcher searched for unexpected and remarkable results. The use of multiple methods contributes to the validity through triangulation. Furthermore, the discussion of the research methods with both supervisors helped in achieving good research methods and higher validity (van Thiel, 2014). Besides this feedback on the research methods, extensive feedback on the entire document was received from several people throughout the process. This resulted in a better and more valid thesis.

3.6.3 Ethics

The final important section of this chapter is on the subject of ethics. Van Thiel (2014) describes five ethical rules regarding Beneficence, Veracity, Privacy, Confidentiality and Informed consent which have all been taken into account for this master's thesis. This means the research should not do harm and should not be misleading. Furthermore, the researcher should respect the privacy of the researched give them the option to refrain from answering questions or the entire interview at any time. Before the interview how the data will be used and stored and that this happens in a confidential manner should be explained. The publication of the research should also be explained. Lastly, explicit permission is needed from the researched to participate in the research (van Thiel, 2014).

4 The context and sociotechnical system of hydrogen filling station implementation

In this chapter the context that is needed to understand the problem and to make an analysis is discussed. Context and concepts are provided on three of the components of the sociotechnical system. These are the physical system (sub question 1), the tasks (sub question 2) and the structure (sub question 3). The first section (4.1) explores the implementation process of hydrogen filling stations and the phase in the transition. The goal is to provide context and sketch the problem further, providing a basis for looking at the sociotechnical system. The second section (4.2) focuses on the underlying concepts and context about mobility and the vehicles. The third section (4.3) touches on the first sub question by discussing context on filling stations and the underlying system with the energy sector. Subsequently, the fourth section (4.4) focuses on the second sub question in which the tasks are discussed. Finally, the fifth section (4.5) focuses on the third sub question, what roles the actors play and how they are related to each other is discussed.

4.1 Implementation, examples of hydrogen filling stations and the transition

This section illustrates the current process and a number of projects regarding hydrogen filling station implementation and the position in the related transition.

4.1.1 Implementation of hydrogen filling stations

In order to identify which steps are taken until a filling station is realised this section explores those steps. Eventually there might be barriers in this process that are discussed in the next chapter.

First of all, the H2Platform (n.d., b) has made an infographic that shows the steps that have to be taken for an entrepreneur to start supplying hydrogen. They determine six phases namely: (1) initiative phase, (2) definition phase, (3) design phase, (4) preparation phase, (5) realisation and (6) operation and maintenance phase. In the initiative phase which usually takes three to six months the first exploration is done. This means doing an environment scan, making a concept budget, exploring the subsidy options, checking the possibilities for permits and checking if it fits in with existing policy. The definition phase takes together with the design phase about six to nine months. It is focused on determining the hard requirements (e.g. safety and land-use plan), operational requirements (e.g. access routes) and commercial requirements (e.g. number and type of vehicles). In the design phase the design is made and the subsidy is requested. After the design is approved the fourth phase starts which takes about three months: the preparation phase. In this phase all the involved stakeholders are brought together. Next is the realisation phase which takes six up to nine months. The utilities are constructed and the components are bought after which the filling station itself is constructed. This is followed by the delivery of the filling station when it is ready for use. Lastly, the operation and maintenance phase take place for which a maintenance plan is made (H2Platform, n.d., b). These are the steps that have to be taken to implement a hydrogen filling station.

The interview with Hemmerlin, provided a lot of information on the product side or the design phase of the implementation process. He identified several steps that have to be taken. First there is a certain request from the customer, that states how many cars and which type of vehicles the filling station must supply. It also states in how much time the vehicles need to be filled and at which pressure. Then the company starts looking at which components are needed. These are four important modules: (1) the buffers, (2) where the hydrogen comes from, (3) the compressor and (4) cooling. The size of the buffer is important because eventually the hydrogen goes from the buffer to the vehicle. Additionally, the compression capacity is important as well as the inlet pressure, at what pressure does the hydrogen arrive. That compression capacity and inlet pressure together determine the size of the compressor that is needed. These four modules together mainly determine the footprint of the filling station. When the footprint is determined it becomes possible to check if it fits at the determined location. This also means looking after the sound restrictions and safety distances. Together all these steps make the first design (F. Hemmerlin, personal communication, April 21, 2020). In the interview with ter Veld additional information on the implementation process was discussed. He mentioned that the process starts with discussing the feasibility of the project and the requirements that can be composed. Furthermore, he stressed the importance of the permit process which takes place with the municipality and the security region (W. ter Veld, personal communication, April 23, 2020).

4.1.2 Examples of hydrogen filling stations in the Netherlands

Now that the implementation process has become clear, the results of such a process can be explored. This section discusses a number of the examples of hydrogen filling station projects in the Netherlands. These are examples of the projects which are currently in development or are completed, there is no aim of creating an overview of all the projects. It is just as an illustration of what has been discussed, in order to get a feeling of what hydrogen filling stations are. The examples have been selected by searching for unique aspects. As a result, the filling station projects in The Hague, Amsterdam and Pesse are discussed.

The Hague

At the Binckhorstlaan in the Hague a filling station has been completed in March 2020. It is located within the city at a light industrial area. Of the three examples presented here, this is the only one that has been completed as of July 2020. It is a normal gas station that has presented hydrogen as the most recent sustainable addition. What makes this example unique is that it is the first multi-fuel filling station in the Netherlands. It provides gasoline, diesel and cng. The filling station is suitable for both 350 and 700 bar vehicles, which gives it a broader range of possible customers. The companies involved besides the owner of the filling station are Stedin, Resato, H2 mobility Europe, and the ministry of Infrastructure and Water Management. Funding from several European projects was also received for this filling station (Fuelcellsworks, 2020). The filling station in the Hague has a large user base formed by 35 hydrogen taxis. Furthermore, 125 hydrogen cars have been ordered in the region for delivery in the first beginning of 2020 (AD, 2019). The combination of multi fuel and a large fleet that make use of the filling station might make it a successful filling station.

Amsterdam

The filling station in Amsterdam is currently in production and was planned to be ready at the end of 2020 (uncertain due to corona crisis). It is a filling station that is being built especially and exclusively for hydrogen. The location is in the harbour of Amsterdam at the Australiëhavenweg (Holthausen, 2020), a location with a large amount of industry nearby. It is relatively close to the highway A5 and in the north west of Amsterdam. The construction of this filling station is combined with the ambition of the municipality of Amsterdam to have an energy neutral municipal car park by 2030. Therefore 6 garbage trucks have been converted to a hydrogen drive train and will make use of this filling station. It was financed with a DKTI subsidy for Holthausen and the municipality contributed €500.000 to it (H2platform, 2019). It seems like this is a good example of combining filling station with end-users.

The filling station will be able to supply hydrogen at both 350 and 700 bar and is thus suitable for cars and trucks or busses. Also suited for filling of cylinders with hydrogen (for industrial use for example). The project also includes the on-site production of hydrogen (Holthausen, 2020).

Figure 4.1: Hydrogen filling station concept for Amsterdam (Holthausen, 2020).

Green Planet Pesse

This filling station project is located along the A28 highway in Drenthe and is a large project with many innovative types of fuel. The gas station itself is already in place but the hydrogen filling station has not been completed yet (in July 2020) (RVO, n.d.). What makes this project unique, besides the multi fuel concept, is the cooperation in the project TSO 2020. This project integrates the hydrogen mobility with the production of electricity. It starts with the production of electricity at sea with windmills with which hydrogen is produced which is then transported to Pesse to be used for mobility. The project itself also includes hydrogen storage in salt domes and the conversion of hydrogen back to electricity that is used for homes. Actors that are involved include Gasunie, TenneT, New Energy Coalition, Energy Stock, Shell and the Technical University Delft. The European Union is involved by providing financial support for the project (Green Planet, n.d.).

4.1.3 The phase in the transition

The transition is one of the central concepts of this master's thesis and therefore it is important to provide context on this subject as well. In chapter 2.3 the diffusion of innovation theory was discussed. This theory is used in this section to describe in which phase the transition towards hydrogen mobility is right now. Figure 4.2 shows the diffusion curve and thus the percentage of potential adopters through time.

The current numbers of hydrogen filling stations and FCEVs is still low compared to their fossil fuel equivalents. The most recent numbers show that there are currently five operational hydrogen filling stations in the Netherlands (H2Platform, n.d., a). This fact makes it quite logical to assume that this transition is still in a very early phase. However, which phase it is exactly needs further analysis. There currently are many filling stations 'in the pipeline' as mentioned by most interviewees. The numbers that are mentioned by them vary but their statements show that there is progress. The most recent numbers show that there are currently 18 hydrogen filling stations being realised in the Netherlands (H2Platform, n.d., a). When these are completed that would bring the total number to 23. Furthermore, the goals set in the climate agreement for 2025 and 2030 give additional insight. By 2025 there should be 50 filling stations in total in the Netherlands (RWS Duurzame mobiliteit, n.d.)). By 2030 that number is aimed to

increase towards 200-300 filling points in total (D. Schaap, personal communication, May 1, 2020). Given the fact that we are at only 5 of the possibly 300 we are still before the take off point. Therefore, it looks like we are between t2 and t3 in the diffusion curve. Looking at figure 2.5, given that we are before the point of critical mass, that means that we are still in the innovators phase in which 2.5% of the adaption takes place.
If this is correct, then this means that the hydrogen mobility transition is still in a very early phase and momentum still needs to be created.

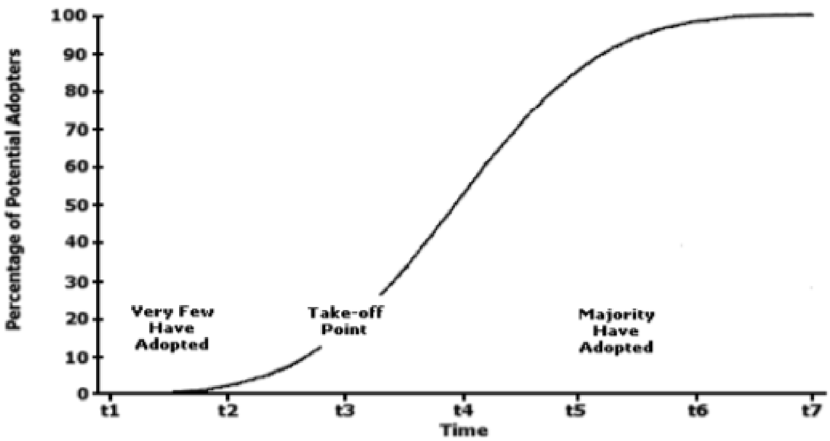

Figure 4.2: The diffusion curve (Adapted by Matinaro & Liu, 2015, from Rogers, 1995, p.262).

4.2 Underlying concepts: mobility and vehicles

This section discusses the relevant concepts available on the subject and the context around it. It provides more depth on some subjects introduced in the introduction. Furthermore, it explains new underlying theory about sustainable and smart mobility before moving on to theory about both battery electric vehicles and fuel cell electric vehicles.

4.2.1 Sustainable and smart mobility

The concepts of sustainable and smart mobility have a strong relevance. In order to go from a to b people need a mode of transport. Many people use cars for their daily commute or other trips. The modal split in the Netherlands supports this claim, because about 60% of the total number of travellers' kilometres is travelled by car. The train takes up 13% and the bike 8% of these total kilometres (Kennisinstituut mobiliteit, 2017). When looking at this from the current context of climate change this number is worrying because most cars, unlike most trains and bikes, use fossil fuels and emit greenhouse gases. However, this can also be seen as a large opportunity to mitigate climate change and might be the origin of sustainable and smart mobility. This is where sustainable mobility comes in, which is quite difficult to define. The definition by Lam and Head (2012) is as follows: "the ease, convenience, affordability and accessibility of travelling to one's destination with minimal impact on the environment and others" (p. 359). This definition shows that there are multiple aspects to it such as social justice, economic sustainability and a minimal impact on the environment. The last aspect is most important to this research. Some vehicles that are currently on the market have a minimal impact on the environment. Electric Vehicles (EVs) are better for the environment than fossil fuel powered vehicles because they do not use fossil fuels and therefore have lower (no direct) emissions (such as nitrogen or carbon dioxide) (Bansal, 2015). There is another subsidiary of mobility, smart mobility, that must be defined to give a more complete picture of the research context.

Smart mobility is often seen as being closely related to sustainable mobility and sometimes even seen as overlapping (Lyons, 2018). This becomes clear from the definition of smart mobility used by Docherty, Marsden and Anable: "a personalized 'service' available 'on demand', with individuals having instant access to a seamless system of clean, green, efficient and flexible transport to meet all of their needs" (pp.114-115). The words clean, green and efficient can be seen as having overlapping aspects with sustainable mobility. Therefore, it can be argued that these two are related. With smart mobility having the addition of the personalized and on demand aspects. These definitions help understanding how mobility is viewed in the literature and how it is viewed as a changing concept. Hydrogen mobility is arguably in itself an innovative, smart and sustainable new concept and therefore these definitions are relevant.

4.2.2 Electric vehicles: BEVs and FCEVs

This paragraph goes into detail on the aforementioned Battery Electric Vehicles (BEV) and also introduces the concept of Fuel Cell Electric Vehicles (FCEV). Both have been explained briefly in the introduction but will be explained more extensively in this section. There are advantages and disadvantages to every type of transportation. According to Bansal (2015) there are some misconceptions about EV's such as that they do not reduce emissions, they will cause high electricity bills, they have low range and they have high production costs. Some of these are valid arguments and they may be (partially) true. However, the cost related arguments are mainly compensated by not spending on fossil fuels and EVs having lower maintenance costs.

Bansal also discusses in his article that wireless in motion charging is a new manner of charging EV's that is still largely in development but might solve range problems (Bansal, 2015). Critiques related to range are the most common problem with electric vehicles, often referred to as 'range anxiety'. Range anxiety means that people are afraid they will not have sufficient range with their car to complete a trip. It can be caused by the batteries having a low capacity or by a lack of suitable charging locations on their route. This is a limiting factor in the sales of EV's (Bonges & Lusk, 2016). According to Bonges and Lusk (2016) it can be solved by improving parking locations, better and clearer chargers, etiquette cards and legislation improvements that for example allow unplugging (Bonges & Lusk, 2016). These might be good solutions but an alternative type of vehicle might provide a more valuable option.

An alternative to the above described problems and to electric vehicles could be hydrogen powered vehicles. One type of these hydrogen powered vehicles that is most common at the moment is Fuel Cell Electric Vehicles. These are in essence Electric Vehicles, but the difference is that a fuel cell creates electricity from hydrogen and only emits water (hydrogen and oxygen become H_2O). This electricity is used to power the car using electric motors in the same manner as a 'normal' or Battery EV propels itself (Alavi, Lee, van de Wouw, de Schutter & Lukszo, 2017). The advantages that FCEVs have when compared to EVs are described by Robinius et al. (2018). They conclude that a combination of both types of vehicles is the best approach for a future vehicle mix. Fuel cell electric vehicles have advantages for long distance travel and heavy transport while battery electric vehicles can take advantage of charging at night. They also state that both types of infrastructures only need a small economic investment as compared to conventional types of infrastructure. Lastly, hydrogen should be seen as an energy system solution by which other industries can be coupled (Robinius et al., 2018). In the section on the energy system this will be discussed further.

There are certain advantages to FCEVs, but what part of the market are they expected to replace? As multiple interviewees mentioned, FCEVs will most likely replace the diesel-powered vehicles while BEVs will most likely replace the gasoline powered vehicles. In the interview with Hemmerlin it was discussed that several sources show that about 25% of the private personal vehicle market will become FCEVs. This roughly matches the amount of true diesel users that use diesel because they travel long distances and not those that only use it because of economic reasoning (F. Hemmerlin, personal communication, April 21, 2020). As was discussed in the interview with Ter Veld hydrogen will likely replace the heavier vehicles that drive longer distances. These are the diesel trucks that would be replaced with FCEV trucks. This is something that has to be considered when designing the filling stations. They need to be accessible for large vehicles such as trucks that have a large turning circle, for example (W. ter Veld, personal communication, April 23, 2020).

Bicer and Dincer (2017) explored the entire life cycle of gasoline, methanol and hydrogen vehicles. This means the life cycle from the production of raw material until actually driving the car. As it turns out, hydrogen is the most environmentally friendly of the three types compared (Bicer & Dincer, 2017). This result shows that environmentally friendliness is an important positive factor for hydrogen. It has to be noted that it is unclear if the hydrogen vehicles referred to in this article are FCEVs or cars with an internal combustion engine that are fuelled by hydrogen. As can be seen in figure 4.3 below, the operation of hydrogen vehicles is only 4% of the total global warming potential. The largest part of the emissions created for hydrogen vehicles, in this case, is in the production of hydrogen via Underground Coal Gasification. This is a non-sustainable type of production which contributes 53% to the global warming potential (Bicer & Dincer, 2017). By using the alternative of electrolysis, this largest part could be removed entirely, provided that green electricity is used.

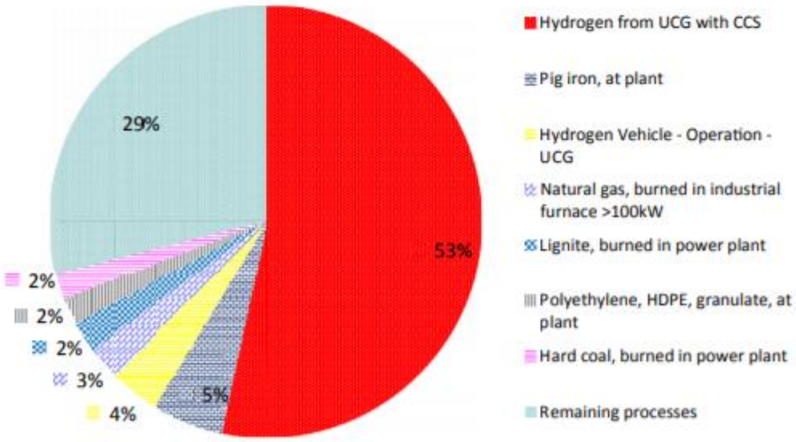

Figure 4.3: Contributions of various processes to global warming potential of hydrogen vehicles (Bicer & Dincer, 2017).

As shown in figure 4.4 below, electric vehicles have a much higher human toxicity per travelled km than hydrogen vehicles. This is mostly a result of the production and disposition of batteries (Bicer & Dincer, 2017). The definitions used in the research of Bicer and Dincer (2017) make it complicated to compare them with those used in this research. Because FCEVs are electric vehicles and thus have batteries as well (although they generally use smaller batteries), the human toxicity can be higher for FCEVs than for the hydrogen vehicles mentioned in general. It is unlikely that the human toxicity of FCEVs could reach the same level as that of electric vehicles.

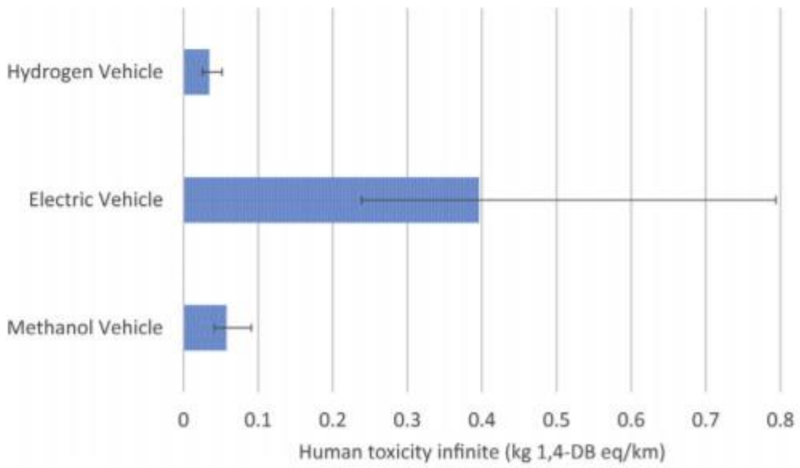

Figure 4.4: Life cycle comparison of human toxicity values of selected vehicles per km travelled (Bicer & Dincer, 2017).

In order for hydrogen cars to be able to drive, hydrogen needs to be produced and the cars need a location to be filled with hydrogen. Therefore, the next section will be on the infrastructure needed for Fuel Cell Electric Vehicles. Furthermore, hydrogen can be a large-scale solution in which the entire energy system could convert to hydrogen, as mentioned before. This larger system infrastructure could be connected to the network of filling stations.

4.3: The physical system: Hydrogen Fuel Cell Electric Vehicle infrastructure

This section discusses the physical system component of the sociotechnical system as has been discussed in the introduction and theoretical framework. The physical system needs to be understood in order to understand the barriers that come from this part of the system. Therefore, this section aims to provide the context needed for this analysis. If a transition to FCEVs were to take place then this would create the need for supporting infrastructure to be developed and built. There appears to be a double-sided relation between the amount of hydrogen cars and the amount of hydrogen infrastructure. This was discussed briefly in the introduction. A low number of cars creates a low demand of infrastructure. The low amount of infrastructure creates a low demand for the cars because there is a lack of infrastructure. This is an equilibrium that needs to be broken in order to create change (Apostolou & Xydis, 2019). Moore and Raman (1998) predicted that the number of cars and infrastructure will initially both be very low and concentrated to certain smaller areas such as Southern California in the United States. They also stated that the amount of infrastructure and the price of hydrogen are also connected because more infrastructure will cause the price to drop (Moore & Raman, 1998). This can possibly result in more demand for the cars and therefore again in more demand for hydrogen refuelling stations. These are barriers that have been discussed in the interviews. Chapter four will go into more detail on this subject and will reflect on the data gathered with the interviews.

4.3.1 The energy system

The larger hydrogen energy system contains the production and transportation of hydrogen from production facilities towards filling stations. Brey, Carazo and Brey (2008) defined that three (or four) important choices must be made for in this case making a hydrogen transition. These choices are which production process is used, which energy source is used for production. Furthermore, it is important to choose between a centralized or decentralized model. Centralized means production on a central location somewhere in the country while decentralized would mean production on the location, for example a filling station. When a centralized model is chosen the method for delivery from the production plant to the filling station must be chosen. On these choices several studies have been done such as one focussed on the transportation of hydrogen in order to supply filling stations, by Lahnaoui, Wulf, Heinrichs and Dalmazzone (2019).

An important first distinction to make is between the three types of hydrogen that are available in the Netherlands. There is a metaphorical colour distinction made by calling them grey, blue and green hydrogen because green is often associated with sustainability. The largest amount of hydrogen currently produced is grey hydrogen. This is created by Steam Methane Reforming where methane (natural gas) reacts with steam and creates hydrogen as well as carbon dioxide. The problem with this technique is the large amount of CO2 that enters the atmosphere. Blue hydrogen is created in the same way as grey hydrogen, except that the CO2 is captured and stored. The CO2 does not enter the atmosphere and thus does not work as a greenhouse gas. Still this is not a sustainable method of production because methane, a non-renewable resource, is used. Green hydrogen however is sustainable and renewable. The most common way of producing green hydrogen is through electrolysis. Electrolysis is the splitting of water in hydrogen and oxygen by using green electricity (TNO, n.d.). The ultimate goal should be that production of all hydrogen is green and from renewable energy sources.

Electrolysis is not always green; it depends on how the electricity is produced. In Canada, a study was done and three types of hydrogen production were used in several provinces. These types of production were electrolysis, thermochemical water splitting and steam methane reforming. All the production methods resulted in less greenhouse gas emissions except for in one province where electrolysis was used. This was a result of the fact that most electricity there was produced using fossil fuels, thus resulting in indirect greenhouse gas emissions. Hydrogen can be produced at a central location or at the filling station itself. This is called on-site and off-site production (Bicer & Dincer, 2017). An addition to the three colours described above is yellow hydrogen. This is hydrogen that would be produced in sunny areas, such as the Sahara Desert. This is then transported to the Netherlands via pipelines or ships (F. Hemmerlin, personal communication, April 21, 2020).

When off-site production is chosen, the hydrogen needs to be transported from the production location to the filling station. At the moment most if not all the hydrogen transportation in the Netherlands is done via tube-trailers according to F. Hemmerlin. These tube-trailers are trucks that carry multiple cylinders. An alternative to this is the use of the natural gas network of the Netherlands for hydrogen. This is the most cost-effective and fast way of transporting hydrogen for the future (F. Hemmerlin, personal communication, April 21, 2020).

An example of the connection of production and filling stations through transportation is the hydrogen backbone that Gasunie has proposed for 2030. This was discussed in the interview with Schaap and it is the plan that a number of the pipelines will be made suitable for hydrogen. These hydrogen pipelines will form a ring in the Netherlands (D. Schaap, personal communication, May 1, 2020). The backbone pipeline would help the hydrogen transition because it would lower the price of hydrogen. Transporting a kilo of hydrogen currently costs 1,5 euros while with the pipeline the cost would be reduced to 10 cents (W. Hazenberg, personal communication, April 21, 2020). While there are multiple advantages to this backbone it also causes several barriers, which are discussed in the next chapter.

Hydrogen can be seen and used as an energy carrier. This means that excess electricity is converted to hydrogen in order to store it more effectively. Hydrogen as an energy carrier was discussed with van der Meij in one of the interviews. She mentioned that supply and demand could be coupled through hydrogen as an energy carrier. Wind and sun energy will be produced and the excess can be saved in the form of hydrogen. Hydrogen is more effective than a large battery because more energy can be contained in a gas than in a battery (T. van der Meij, personal communication, 21 April, 2020). Hydrogen as an energy carrier could result in the production of hydrogen on a larger scale, which in turn could benefit hydrogen mobility through a lowered price. As Schaap mentioned, when hydrogen becomes more important in the economy production of green hydrogen will happen on a larger scale and that hopefully will result in a lower price (D. Schaap, personal communication, May 1, 2020).

4.3.2 Hydrogen filling stations

The main part of the physical system for this research are the hydrogen filling stations themselves. According to the most recent data there are currently five public operational hydrogen filling stations in the Netherlands and 18 more that are planned or being constructed (H2Platform, n.d., a). The distinction between public and non-public filling stations is important. Data from the Benelux shows that there were also several non-public filling stations in the Benelux (Waterstof Net, n.d).

Not every filling station is the same, therefore there are different approaches to them and different techniques that are used. There are differences regarding the pressure used for filling the vehicles' hydrogen tank (350 or 700 bar) and as a result if the filling station is suitable for busses and trucks, cars or both. Generally, trucks and buses use 350 bars while cars use 700 bars (Waterstof Net, n.d.). Another distinction made between two types of filling stations is based on the size. Resato produces both small fleet owner stations as well as full sized stations (figure 4.5). The fleet owner station has a lower capacity of 4kg per hour and has a footprint of 16 square meters. The full-size station has a capacity of over 20kg per hour and is much larger. Additionally, it is also suitable for filling large vehicles at 350 bars while the fleet owner station can only supply 700 bar and small vehicles (Resato, n.d.). These two are just examples of the different filling stations that can be produced, there are additional sizes and distinctions made by other companies.

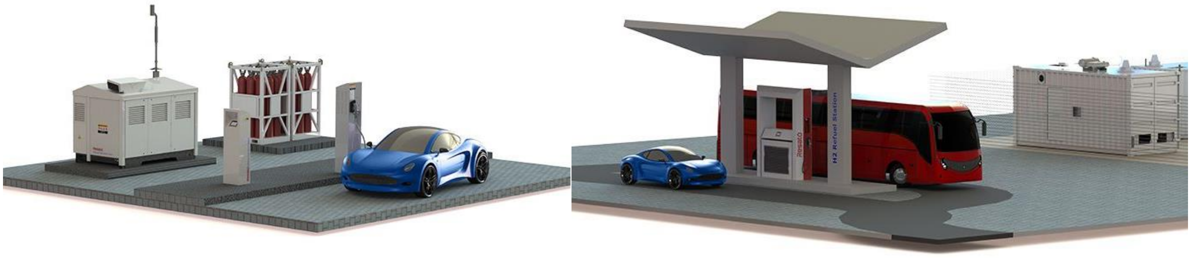

Figure 4.5: The fleet owner filling station on the left and the full-size filling station on the right (Resato, n.d.).

As discussed before in the previous section, there can be centralized or decentralized production of hydrogen. In other words, this means on site production of hydrogen or off-site production of hydrogen. The choice between these two has an influence on the systems that must be put in place at the filling station.

In figure 4.6 all the technological elements that are needed at a filling station are shown in a diagram. In the figure the onsite system is shown starting with electrolysis or steam methane reforming production. The off-site hydrogen system replaces the first two steps with transportation while the rest of the diagram from storage onwards stays the same (Apostolou & Xydis, 2019). The second step in the figure is a hydrogen purification system. A purity of at least 99,97% is needed for supplying fuel cells (Apostolou and Xydis, 2019). This has implications for the type of transport to the filling station when off site production is chosen. When the natural gas pipeline network is used, every filling station would probably need this purification system. Impurities that once were in the methane that was transported through the pipelines might have been left behind in the pipelines. These might contaminate the hydrogen when it is transported through it. The alternative is transporting pure hydrogen on the road (F. van de Watering, personal communication, April 29, 2020). The third step is low pressure hydrogen storage. This is where the hydrogen is stored initially after it is delivered or produced. The fourth step is a hydrogen compressor that compresses the hydrogen to the 350 or 700 bars needed for the vehicles. The fifth step is high pressure hydrogen storage where the compressed hydrogen is stored. The hydrogen can be stored in the form of a gas or as liquid. An advantage of the high-pressure storage is that it takes less space than the low-pressure storage. The sixth step is a hydrogen gas booster, which regulates the pressure while the refuelling takes place. The seventh step is a hydrogen cooler system which is needed for safety. During the refuelling, the hydrogen gas tank can become warm and to keep the temperature low the hydrogen gas is cooled. The eighth and final step is the hydrogen dispenser itself. These look much like those used at normal gas stations. Additionally, there are safety and connecting components that are needed at a filling station. These are sensors, piping, valves, fire suppression and electrical equipment (Apostolou & Xydis, 2019). This large number of components makes the hydrogen filling station a complex technological product.

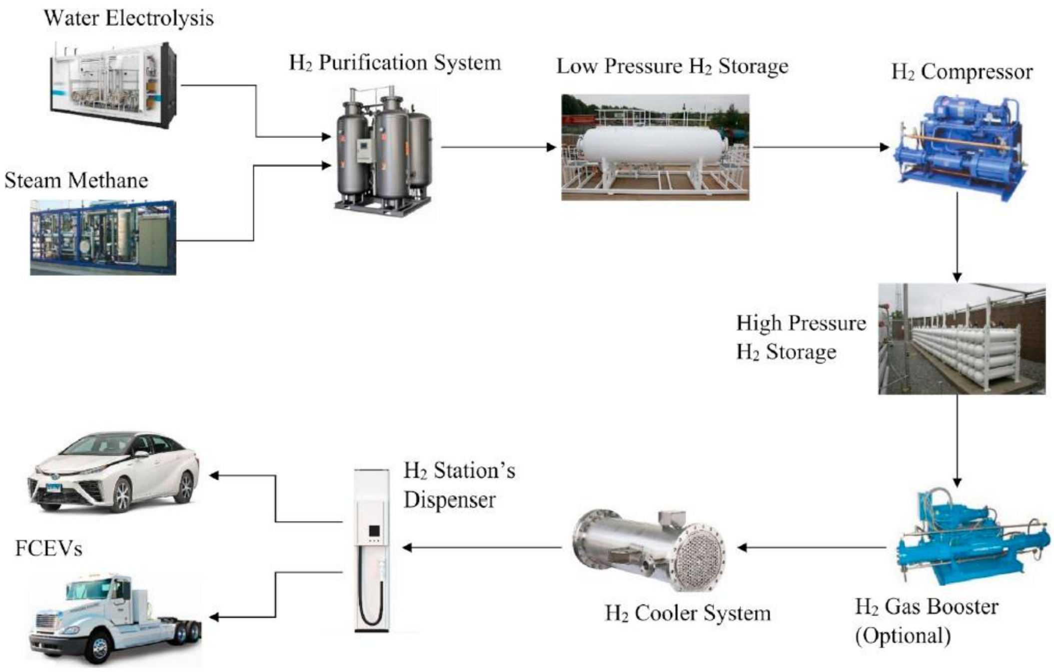

Figure 4.6: The off-site hydrogen filling station system (Apostolou & Xydis, 2019).

Another categorization is whether the filling station can only supply hydrogen or if it is combined with a normal gas station. In other words if it is a stand-alone or a multifuel filling station. Hemmerlin mentioned in the interview that the first real multifuel filling station in the Netherlands is the one Resato built in the Hague. It is important that the filling stations become multifuel in order to create a better business case (F. Hemmerlin, personal communication, April 21, 2020). Arguably, the eventual goal is that hydrogen is supplied at normal filling stations. There will not be many entrepreneurs who will choose to start supplying only hydrogen. The business case becomes better when offering multiple fuels but there are also disadvantages to multifuel. It is more difficult safety wise because the proximity of other installations can cause interferences for the hydrogen installation. If something happens to an electric charging facility next to the hydrogen filling station, then this might have effects on the hydrogen filling station. This is something that must be considered (D. Schaap, personal communication, May 1, 2020).

Smart Grid

The filling stations as discussed above are quite similar to the gas stations we have today. You go to a location to fill your car. An alternative to the scenario in which there are filling stations at set locations is the use of FCEVs as a micro-power plant, complementing the electricity grid. Alavi, Lee, van de Wouw, de Schutter and Lukszo (2017) call this a micro-grid in which in combination with wind and solar energy fuel cells can provide energy when renewable energy is hard to come by. When excess renewable energy is created, for example when there is an above average sunny or windy day, this energy can be stored in hydrogen. The hydrogen can then later be used to power a car's fuel cell for mobility or to power a house (Alavi, Lee, van de Wouw, de Schutter & Lukszo, 2017). The possibilities and viability of this alternative has been discussed with interviewees and this will be reflected upon in chapter 5.

Sub conclusion

In this chapter the physical system component of the sociotechnical system and with that the first sub question were discussed. The physical system is the technological side of the hydrogen filling stations and the hydrogen mobility transition. The components that are part of the filling station were identified, as well as a theoretical context focussing on the vehicles. There is a large amount of complexity that goes into the physical system. This complexity or the choices that have to be made regarding the categorizations might be the origin of barriers. These barriers are explored in chapter 5.

4.4 Tasks

The task component is the second component of the Social Technical System that will be discussed. The task must be explored to answer the second sub question. In chapter 2 the task component was operationalised as the '*capabilities of the sociotechnical system or in other words things that people do and that the technology is capable of doing'*. These tasks might be the cause of a number of barriers that limit the hydrogen mobility transition. These barriers can be the cause of tasks that the system must perform but is unable to perform. The tasks component is difficult to grasp and to explain. For a large part it has been implicitly touched upon in the chapters 4.1 and 4.2. Furthermore, there is overlap with the barriers and opportunities of chapter 5. Therefore, the tasks will not be discussed extensively.

A distinction can be made between tasks for production, transportation and the filling station itself. The hydrogen production facility needs to meet certain requirements such as producing enough hydrogen for the right price. The transportation needs to meet certain requirements also related to the price, the capacity or speed and quality. The hydrogen filling station needs to meet certain requirements such as quickly filling the vehicles, having enough capacity to reach demand and safety.

What becomes visible from this distinction is the relation and resemblance with the four factors that were identified in chapter 2. Namely the economic, safety, location and social factors. When looking at these more closely the economic factor is the price of transportation or hydrogen itself, safety remains clear, location can be seen as accessibility and the social factor resembles public support.

Furthermore, from the definition of sustainable mobility by Lam and Head (2012) introduced in chapter 4.1 several components of sustainable mobility became clear. These are ease, convenience, affordability and accessibility. These are tasks that a hydrogen filling station must fulfil in order to facilitate sustainable mobility. It needs to provide the service in a way that is easy and perhaps practically usable for customers. It needs to be convenient for users, a practical example of this could be a shop or workplace at the filling station. Affordability is the price that has already been mentioned before. Accessibility is the location; a large vehicle needs to be able to physically access the filling station and it has to be along the route.

These tasks have shown that there are a number of services that are expected of a hydrogen filling station. Not meeting these could form a barrier for the hydrogen filling station transition. For this reason, the tasks are also discussed in chapter 5.

4.5 Actors and the market structure

In order to answer the third sub question about the structure component and relevant actors, an understanding must be created of which actors are involved in the implementation of hydrogen filling stations and what roles they play. Furthermore, it is also necessary to understand how they are related to each other, the interplay between them which is the market structure. The theory introduced in chapter 2.4 (Avelino & Wittmayer, 2016) in which four sectors are identified (state, market, community and non-profit) is used to subdivide the actors.

4.5.1 Actors

As starting point the guideline made by H2Platform is used in which several actors are identified. First of all, an entrepreneur is needed who takes the initiative for the development of a hydrogen filling station. The second important actor is the municipality which makes a land-use plan and has responsibility for the permits. Third is the omgevingsdienst (environmental service) which also works on granting the permits and is a state actor. Fourth is the subsidy provider, which often is the National government through the DKTI or the EU. Fifth is a contractor who is responsible for constructing the filling station. Sixth is the supplier of technological components, such as the compressor and the other components described in section 4.1. Seventh is the utility provider. And eight are the fleet owner or customers that have cooperated with the project (H2Platform, n.d., b). The list of actors from this source provides a good base to start from. To identify more actors and to elaborate on the roles the interview data is used. Not every actor will be explained and discussed here because some of them have limited roles in the implementation process, these are the omgevingsdienst (state) contractor (market) and utility provider (market). They are needed for building the filling station but have a limited role.

Initiator or entrepreneur (Market or community sector)

For a filling station to be built, at first someone must take the initiative for it.
As Hemmerlin discussed you need an entrepreneur who dares to look forward, who is enthusiastic about the subject and needs to have a pioneer mentality (F. Hemmerlin, personal communication, April 21, 2020). In the interview with van der Meij the possibilities for other initiators such as normal citizens were discussed as well. Filling stations are quite specialistic and therefore probably normal citizens or groups of them will not take the initiative. They are done by entrepreneurs who may have experience in the gas station market (T. van der Meij, personal communication, April 21, 2020). As the example from the Hague showed a gas station owner can also take the initiative to add a hydrogen filling station to his existing gas station. Besides entrepreneurs the initiators can be large companies, in the industrial sector for example (F. Hemmerlin, personal communication, April 21, 2020).

Fleet owner or customer (State, market, community or non-profit sector)

The fleet owners or customers are one of the first actors that should be engaged with, together with the municipality. This is what essentially would be the people component from the sociotechnical system, that is not discussed in this research. It is however of added value to make a limited description of them as an actor.

If an entrepreneur can assemble a large group of customers or a fleet owner, then less subsidy is needed. Such as a taxi company that uses the hydrogen filling station for their vehicles (F. Hemmerlin, personal communication, April 21, 2020). But a customer can also be the municipality that needs garbage trucks or just a citizen who needs a car. The customers create the demand and eventually are going to pay for filling their vehicle with hydrogen, thus making the filling station necessary and viable.

Component suppliers: Resato, Pitpoint etc. (Market sector)

To build a filling station, companies that supply the technical components are needed. In the Netherlands there are several companies who supply these components, such as Resato, Pitpoint or Holthausen. An interview with Hemmerlin of Resato was held in which the role of the company as a component supplier was discussed. Resato is specialized in high pressure technology and provides complete filling stations for customers. Which components are supplied exactly can be read in chapter 4.1.2 (F. Hemmerlin, personal communication, April 21, 2020).

Hydrogen supplier (Market sector)

As has been discussed earlier in chapter 4.1, hydrogen can be produced on location or somewhere else. The hydrogen that is sold at the filling stations needs to be supplied by an external actor if there is no production on location. They play an important role because the hydrogen is essential for the operation of the filling station.

The different production methods for hydrogen, as discussed in 4.1 influence the eventual price for hydrogen. Some of the methods are still expensive. When the hydrogen price is reduced, the economic viability goes up (F. van de Watering, personal communication, 29 April, 2020).

Transportation (Market or state sector)

In chapter 4.1 the transportation was discussed as well. If an external company supplies the hydrogen, then this must be transported to the filling station in some way. Either by pipeline or by truck an actor must be found to supply this service.

The transportation type influences the hydrogen price as well. The transportation via pipelines would be very affordable (F. van de Watering, personal communication, 29 April, 2020).

Vehicle manufacturers (Market sector)

The vehicle manufacturers are not directly involved in the implementation of filling stations but they are involved in the transition. The lock-in situation is partially due to a lack of vehicles, as described in the introduction. Their role is providing enough and affordable vehicles. As Hemmerlin discussed they are arguably not involved enough at the moment. The faster they produce vehicles, the more serious people will consider buying a hydrogen vehicle (F. Hemmerlin, personal communication, April 21, 2020).

Municipality (State sector)

The municipality is an important actor in the implementation of hydrogen filling stations, as mentioned earlier. The municipality makes a land-use plan and other policy documents and provides the necessary permits. It is arguably the first actor that must start with (F. Hemmerlin, personal communication, April 21, 2020). The interview with Beekman, was used to learn more about the role of the municipality in the implementation of filling stations. He discussed additional roles that the municipality can have. One of these is the role of a municipality as the landowner. This means that they sell or rent land to gas stations or filling stations. This makes it a large source of income and a valuable role to play. What a municipality can also do is expressing an administrative desire and exert administrative influence through speaking and meeting with people (R. Beekman, personal communication, May 7, 2020). The permission process requires contact with the municipality and the safety region. The municipality provides the permit but they do not always have the right knowledge, that knowledge is provided by the safety region (W. ter Veld, personal communication, April 23, 2020). Another role that the municipality plays comes from the municipal remediation policy. The municipality controls the number of permits for gas stations (or filling stations) there are. This means that some new gas stations might not get a permit (D. Schaap, personal communication, May 1, 2020).

Safety Region (Veiligheidsregio) (State sector)

As discussed at the municipality part, the safety region plays an important role in the permit process. The safety region has a lot of knowledge about safety and will give advice to the municipality on the permit for a filling station (W. ter Veld, personal communication, April 23, 2020).

Province (State sector)

The role of the province in the hydrogen mobility transition was discussed in the interview with Horbach who works on the subject of hydrogen at the Province of Utrecht. She works on creating clean energy hubs along the freight corridors in the province of Utrecht. These are refuelling stations for alternative fuel types, including hydrogen. The main roles of a province are facilitating, boosting demand, connecting and sometimes being a launching customer. Their role is not to build filling stations themselves, that is not their role and they will not do that. A province would never be shareholders for a filling or gas station. One of the main roles is to facilitate the creation of clean energy hubs that are aligned with the province’s goals for making freight transport sustainable. Facilitating is where it all starts, it is what makes building a filling station possible. Another part of the role of the province is trying to connect the different actors that are involved (with in this case filling station implementation) and connecting their own policy fields as far as possible. They play a connecting and mediating role in conflicts of interest between these actors. This includes cooperation with other provinces and municipalities and knowledge sharing. Furthermore, the province tries to boost demand and supports parties that boost demand. The province can help as a launching customer but there is no policy for that yet. Being a launching customer would mean creating demand by buying hydrogen vehicles themselves. This creates attention and puts it on the agenda. One of the instruments the province can use is granting subsidy which the province of Utrecht for example currently does not do. Technically it could be possible for a province to do that and Gelderland currently provides subsidy for hydrogen trucks (R. Horbach, personal communication, April 28, 2020). This information shows that the province as an actor in the state sector is focused on connecting the other actors and facilitating their cooperation and actions.

Ministry of Infrastructure and Water Management (State sector)

The role of the ministry of Infrastructure and Water Management consists partially of converting the national political vision into policy. They make an implementation strategy and implement the climate agreement which contains several goals and ambitions. The ministry tries to make sure that these goals and ambitions are carried out. The ministry does not have direct influence but can for example use subsidy to exercise influence. These subsidies are aimed at helping speed up the construction of filling stations and making the vehicles more affordable. The subsidy for filling stations is called DKTI. Another part of the role of the ministry is detecting problems and attempting to solve them such as with the municipal remediation policy. The ministry attempts to create the right conditions for implementing and building the filling stations. It is important that they leave a lot of it to the market and often provide subsidy after the filling station is built (D. Schaap, personal communication, May 1, 2020).

Rijkswaterstaat (State sector)

The illustration of the role of Rijkswaterstaat comes from the interview with van den Berg and Scheffer who work on sustainable mobility at Water, Verkeer and Leefomgeving at Rijkswaterstaat. Rijkswaterstaat is the implementing organization of the Dutch governments' Ministry of Infrastructure and Water Management. Providing support in projects, setting up projects and sometimes setting up projects. The direct role for the team sustainable mobility specifically is to give advice to the ministry. Through giving good advice they can influence the transition indirectly, resulting in no delays or in other words a positive effect. However, they do not have the authority to make the decisions. Another relevant role of Rijkswaterstaat is working together with provinces on identifying suitable locations for filling stations. Rijkswaterstaat is responsible for the main road network in the Netherlands and the services related to that. That includes the rest areas where people can park their car, which often have a gas station as well (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). Because they are responsible for the gas stations at the rest areas, they have influence on them. This is also illustrated by Schaap in his interview. Rijkswaterstaat is the concession provider for these areas and could therefore make requirements to gas stations (D. Schaap, personal communication, May 1, 2020).

EU (State sector)

The EU plays a significant role as subsidy provider for hydrogen filling station projects. There are several European projects such as H2Nodes and H2Benelux, which were also mentioned in the interview with van den Berg and Scheffer. These projects are realised with European support from the Connecting Europe Facility (CEF) which is a financing mechanism for the Ten-T (Trans European Transport Network). Rijkswaterstaat helps these projects with choosing a location for filling stations (N. van den Berg & S. Scheffer, personal communication, May 8, 2020).

Table 4.1: Overview of the actors that are involved in hydrogen filling station implementation.

Actor	Sector	Role	Tools
Initiator	Market, Community	Initiating the implementation	-
Fleet owner/customer	State, Market, Community, Non-Profit	Creating hydrogen demand	-
Component supplier	Market	Supplying the components	-
Hydrogen supplier	Market	Supplying the hydrogen	-
Transportation	Market, State	Transporting hydrogen	-
Vehicle Manufacturers	Market	Building vehicles	-
Municipality	State	Implementing in plans and permit process	Land use plan, Permits
Safety region	State	Ensuring safety and advising the municipality	Advise
Province	State	Connecting and facilitating	Subsidy, mediation, launching customer
Ministry I&W	State	Creating policy, guidance, subsidy	Policy, projects
Rijkswaterstaat	State	Advice the ministry, responsibility for roads and rest places	Projects and concessions
EU	State	Guidance and subsidy	Projects

4.5.2 Actor characterization

In table 4.2 below the actors have been characterized using power, legitimacy and urgency as defined by Mitchells, Agle and Wood (1997). The choices regarding the actors from the state and market sectors will be explained. Generally, the power of the state actors (municipality to EU) is high, because they have a lot of influence through the tools they can use. Their legitimacy is high as well because they are legitimate entities in the Netherlands. Their urgency is medium to high because they all have programs or intentions to work on hydrogen filling stations. The urgency can differ between specific provinces or municipalities because they are autonomous and can make different choices regarding their visions.

The actors withing the market sector (Initiator to vehicle manufacturers) has differing power levels. The initiator does not have much power because they are dependent on many other actors. The fleet owner has high power because they have a large influence on the business case for the filling station. The component supplier and transportation actors have medium power because they are both dependent on the construction of a hydrogen filling station as is the hydrogen filling station of them. The legitimacy of these actors is difficult to determine because it depends on the specific actor if they are legitimate. For example one initiator can be viewed generally as illegitimate while another renowned entrepreneur might be viewed as legitimate. Therefore, in the table the legitimacy was not rated as high or low but was varied. Most market actors will see the transition as an opportunity and will want to make profit thus having high urgency as a result. If the specific actor is involved in the filling station implementation already or has a large ambition for it, the urgency is rated high. If they are not involved, they might not want to make the transition and might have low urgency. A transition costs money and sticking with the current market might give them more short-term profit.

Table 4.2: Characterization of the actors with power, legitimacy and urgency based on Mitchell, Agle and Wood (1997).

Actor	**Power**	**Legitimacy**	**Urgency**
Initiator	Low	Varied	High
Fleet owner/customer	High	Varied	Varied: High if they are eager to get involved, lower if they are not.
Component supplier	Medium	Varied	High: If they are involved then they will want to make profit.
Hydrogen supplier	High	Varied	High: A profit can be made by selling more hydrogen.
Transportation	Medium	Varied	High: A profit can be made by transporting more hydrogen.
Vehicle Manufacturers	High	Varied	Varied: The manufacturers that already have hydrogen cars have a high urgency while those without have lower urgency.
Municipality	High	High	Varied: Different per municipality.
Safety region	Medium	High	High
Province	Medium	High	Varied: Different per province.
Ministry I&W	High	High	Medium
Rijkswaterstaat	Medium	High	Medium
EU	Medium	High	Medium

4.5.3 Market Structure

The market structure is discussed by looking at the relations between the actors. All in all, the analysis of these different actors shows that they all seem to be linked by the initiator. Furthermore, it becomes clear that a lot of the relationships with governmental actors are based on funding or permits. The Province, Ministry and EU all give subsidy and aim to fund the projects. Another number of actors can be grouped as a technical group which is involved with constructing the filling station itself. These are linked to the initiator once again because they supply the parts needed for the filling station. The supply of hydrogen and transportation is an additional external relation on which the filling station depends. The fleet owners or customers are an important relation as well because without them the filling station cannot generate income. The customers are in turn dependant on the vehicle suppliers who create the vehicles these customers use. Regarding the theory from chapter 2.4 it can be concluded that the state actors are mostly engaged with subsidy and permits but are not engaged with building the filling stations and the technical group are predominantly market actors.

Furthermore, it is important to determine if there is transition in the market structure. Perhaps certain actors can play different roles than they do currently. Several interviewees pointed out that the government could change the role they play in the filling station implementation and hydrogen mobility transition. They could perhaps take a more top-down or leading role. Taking the lead in the form of more or different subsidy or giving more guidance could improve the hydrogen mobility transition.

An example of this is what ter Veld points out in his interview. He believes that the government should play a more leading role. Because leaving it to the market could facilitate some actors who want to retain the current industry. The government can take a pioneering role and introduce the shift towards hydrogen while emphasizing that it is a shift to a new industry. The new industry will also need to be developed and maintained, therefore these actors are needed for that as well (W. ter Veld, personal communication, April 23, 2020).

From the analysis in in chapter 4.5.2 it became clear that the state actors have a high power and legitimacy combined with a considerable urgency. Based on these results it could be concluded that the government or state actors could make the largest difference to filling station implementation.

While letting the government take a more leading role seems to be a good solution, this is likely a step the government is very cautious on taking. In the Netherlands, the government prefers not to take the lead because of the neo-liberal system that is in place. The government would most likely want to leave it to the market (Needham, 2006, p.22). The illustration of this opportunity and barrier regarding the role of the government leads the way to the next chapter that focuses more on these opportunities and barriers.

5 Barriers & opportunities

In this chapter the main data that was gathered with the interviews is discussed. The chapter focuses on sub question four: the opportunities and barriers in between the components. The three components of the sociotechnical system that were discussed in the previous chapter influence each other, from which barriers and opportunities can be identified. This was also shown in the conceptual model. The first section goes into detail on the factors that were identified in the theoretical framework and additionally the spatial effects of a filling station are explored. The second section focuses on the opportunities and barriers that come into play in this transition.

5.1 The four factors and spatial effects

The four factors that were identified in chapter 2 are discussed here: economic, safety, location and society. During the interviews, questions were asked about these factors, regarding their influence on the filling station implementation and the transition and how to deal with them. The spatial effects are discussed here as well because they are closely related to the factors.

Economic (business case)

The influence of the economic factor was important because it is related to the business case. This determines the economic viability of a filling station. Also, the attractiveness of using hydrogen is determined by the price. Mobility could help facilitate a lower hydrogen price by lowering it and making it attractive for other industries as a result (F. van de Watering, personal communication, April 29, 2020).

It is still difficult to create a good business case for hydrogen filling stations. This is a result of a lack of customers and that the equipment is still expensive. The costs are high and it takes long to earn them back with a small number of customers (W. ter Veld, personal communication, April 23, 2020). This is further illustrated by the statement that subsidy is almost always still needed for filling stations. But if there are many customers, less subsidy is needed to complete the business case (F. Hemmerlin, personal communication, April 21, 2020). Another solution for completing the business case is trying to appeal to multiple customers. This means not detaching passenger and freight transport and letting them fill their vehicles at the same filling station. Additionally, offering multiple fuels at the filling station can also improve the business case (R. Horbach, personal communication, April 28, 2020). If it is not economically viable to build a filling station, likely little will be built thus contributing to the lock-in situation. Because a lack of filling stations means insecurity resulting in a lack of hydrogen vehicles. The subsidies described in chapter 4 are a way of making sure that the filling stations get built anyway, even though the business case can not be completed. Therefore, this seems to be an important measure to ensure the construction of filling stations.

Safety

The safety of the filling station is an important factor and how safety influences the transition and the filling station was explored. In general terms safety was discussed in the interview with van der Meij. She mentioned that in the Netherlands we are used to natural gas and that hydrogen is quite similar. Hydrogen is also a flammable gas, but it has slightly different characteristics such as that the hydrogen flame is invisible. In order to counteract these differences safety measures have to be taken. An example of a measure is the need for a different detector because the hydrogen flame is invisible. Another possible safety hazard is preventing people from tinkering at home with hydrogen. All in all, it was argued that hydrogen is at least as safe as natural gas but that it needs to be treated differently (T. van der Meij, personal communication, April, 21, 2020). Hazenberg agrees that the safety of hydrogen is comparable to natural gas, but it is not always 1 on 1 comparable. For home heating applications a low pressure is used, which is not the case for mobility applications (W. Hazenberg, personal communication, April 21, 2020). Looking more closely at mobility, as van den Berg mentioned, the most important safety implication for mobility is the high pressure that is used. This high pressure requires specialistic knowledge and handling. The European rules state that the best available techniques must be used and for the Netherlands that is the PGS35. This is the most important ruleset which must be followed (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). Another interesting safety aspect is checking the quality of the hydrogen. This is done to guarantee that the fuel cell does not break down as a result of contaminated hydrogen. Additionally, an emergency button at the filling station is another safety aspect that is important (F. Hemmerlin, personal communication, April 21, 2020). Lastly, the viewpoint of the ministry of infrastructure and water management is that hydrogen in mobility is necessary but it must be safe. There are still some uncertainties with the safety aspects of hydrogen filling stations. Carefulness is required and therefore the safety distances must be taken into account. It is not a stationary process, we keep researching as we get more knowledge the distances might be decreased. This is done through the hydrogen safety innovation programme (WVIP) which is a large programme that will address and tackle hydrogen safety aspects for the next four years (D. Schaap, personal communication, May 1, 2020). All in all, the safety factor is important to take into account but it does not seem to be a large direct source of barriers. Most of the safety implications are already dealt with or there is a strategy available on how to deal with them, from rules and regulation.

Location

The location of filling stations was researched to find what influences the most likely locations for filling stations. The first projects were often located at a place where hydrogen is available in some way. This can be closet to a factory that produces hydrogen as a waste material or close to an already existing pipeline. Currently it is logical to locate a filling station nearby a fleet owner (F. Hemmerlin, personal communication, April 21, 2020). This is the most convenient for the customers.

A current trend is that filling stations are more often located at logistical hotspots or business parks instead of at locations along the highways. It is important that the location does not cause extra movements. For filling stations aimed at trucks that means that locations along the most important freight corridors could be likely (R. Horbach, personal communication, April 28, 2020). Some of these freight corridors have a larger volume and might therefore have a bigger chance of having hydrogen trucks driving on them (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). Locations on these large volume corridors seem therefore more likely than along low volume corridors.

Combining the location with the transportation of hydrogen further implications are identified. If the hydrogen backbone gets realised it would be smart to build a filling station at a location where the backbone intersects with a highway. A location close to this backbone means that a short pipeline is needed, which is more affordable and can supply almost unlimited amounts of hydrogen. Furthermore, a small buffer at the filling station is needed, which is easier for the safety and permits (W. Hazenberg, personal communication, April 21, 2020). Schaap

mentions the same locations as the other respondents: nodal locations near heavy duty corridors and combining it with the underlying energy system (backbone). Additionally, he mentions that hydrogen filling stations could possibly be located near local hydrogen production locations (D. Schaap, personal communication, May 1, 2020).
Concludingly it can be said that viable locations for hydrogen filling stations are near logistical hotspots, near highways and near the backbone in the future or near production facilities. Probably, places where all these factors can be combined are the most viable for a long-term hydrogen filling station location. It does not seem to be a large influence on the barriers.

Society

The society factor was explored and the actors were asked about their views on society and public opinion and how they deal with it. Something that is often stressed is that hydrogen is not a panacea. It can be a good addition and solution in some applications but should not be expected to be that in all cases. It is not necessarily the end solution for mobility for cars because the batteries keep getting better, but it could be a good solution for heavy transport. There are multiple ways in which people can be informed about a new concept such as hydrogen. A way of informing people is giving hydrogen clinics (T. van der Meij, personal communication, April, 21, 2020). Van de Watering works on informing people about hydrogen by giving 'hydrogen for dummies' presentations that are very practical presentations aimed at providing people with an objective image of hydrogen. They include letting them make hydrogen and showing that a small car can drive on it.

More practically related to the implementation of filling stations people need to be informed when a filling station is constructed near them. This is mainly done though newsletters and information evenings. These are aimed at giving information and really showing what will happen at that location (W. ter Veld, personal communication, April 23, 2020). Hazenberg adds that informing people is always good but not always the problem. He agreed that organizing information evenings with many applications related to hydrogen present (from cars to stoves) are a good way of informing the public (W. Hazenberg, personal communication, April 21, 2020).

The roles of the government in informing the public are currently limited. Rijkswaterstaat does not really have a task in this but they do have their own web page with information and sometimes work on dissemination for projects in which possible customers are informed (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). Likewise, the ministry of Infrastructure and Water Management does not have a large-scale communication programme to make the civilians get used to hydrogen. However, Schaap also mentioned that in his experience there is not much resistance to the implementation of hydrogen filling stations either, from civilians' perception of unsafety. People seem to think that if filling stations are built, then they are is most likely safe as well. A way in which civilians can indirectly get accustomed to hydrogen vehicles is subsidizing visible applications close to people, such as garbage trucks. This could make people realise that hydrogen garbage trucks are very quiet compared to normal ones (D. Schaap, personal communication, May 1, 2020).

Research seems to agree with the findings above that point in the direction of a positive public opinion on hydrogen. In 2012 Zimmer and Welke (2012) researched the general public's perspective on hydrogen powered cars in Germany. In general, almost 80% of the Germans are in favour of introducing these cars. They praise the high mobility without harming the environment. However, the hydrogen must be produced with renewable energy to be emission-free. Also, possible danger involved with hydrogen fuelling stations was not a problem for the public (Zimmer & Welke, 2012). All in all, the public opinion seems to be positive but it remains important to inform the public about a new, relatively unknown concept as hydrogen.

Spatial effects and implications

Now that the factors have been explored, a step towards a more tangible section can be taken. From a spatial planning point of view, it is interesting to discuss what the spatial effects are of the implementation of a filling station. In this way the results of building a filling station can be made more concrete. First of all, the safety distances are an important factor in this. They need to be checked. Furthermore, the unloading of hydrogen needs to stay separated from the dispenser itself. When a hydrogen filling station is connected to a pipeline then there will be spatial effects when that connection is made (T. van der Meij, personal communication, April, 21, 2020). Hemmerlin emphasizes that a lot of space is needed for delivering hydrogen to a filling station by tube-trailers. The place where you unload hydrogen can not be the same as where you fill your car. Also, unloading the hydrogen takes time, it is not just a 10-minute process. These factors influence the supply route and the local infrastructure around the filling station (F. Hemmerlin, personal communication, April 21, 2020). The importance of the safety distances was discussed more by ter Veld by stating the internal and external safety distances have a direct influence on the surroundings. A distance of about 35 meters is needed from the most critical point around the entire filling station. As a result, making the filling station fit in the available space may take some time (W. ter Veld, personal communication, April 23, 2020). A difference with the contemporary gas stations is that for a hydrogen filling station the storage tanks are above ground instead of underground. Apparently, bringing them underground is not possible yet. It is agreed upon that because a hydrogen filling station is quite space intensive, it is difficult to implement. Furthermore, like van der Meij mentioned, when hydrogen pipelines are used spatial effects must be accounted for. To place them underground, large parts of the Netherlands would need to be dug open. Furthermore, it raises questions about if they can be placed under the streets or if special streets are needed. Also, possibly safety distances could be needed around the pipelines. Hydrogen transportation through pipelines therefore has large effects on the spatial implementation as well (D. Schaap, personal communication, May 1, 2020). It can be concluded that the spatial effects are mainly caused by safety measures for both the filling station and the transportation method. These physical system related insights have an influence on the hydrogen filling station implementation.

5.2 Barriers and opportunities

In this section the barriers will be discussed while at the same time discussing the opportunities that are proposed for these barriers. After the barriers some additional opportunities will be discussed. Some of the barriers show some overlap because of the complexity of the causality of some barriers. One barrier might be the cause of another barrier. When a relation with the theory was found this has been illustrated at the respective barrier or opportunity.

5.2.1 General barriers and opportunities

Business case

First of all, the business case can be seen as one of the largest barriers that limit the filling station implementation. In most interviews this barrier was discussed, and that the business case can not be completed yet. Ter Veld mentioned that the business case is not there at all. The filling station components are still expensive because they are not mass produced yet, it is not a standardized product. That does not mean that the components are improvised either. As a result, a filling station is expensive to build. Earning back the money spent on building it takes a long time with a small customer base of a few hundred hydrogen vehicles. The subsidy provided by the government is used to lower these costs (W. ter Veld, personal communication, April 23, 2020). In addition, Hemmerlin too mentioned that the price of hydrogen is too high and that the price of the components needed for a filling station is too high (F. Hemmerlin, personal communication, April 21, 2020). Perhaps increasing this subsidy is an opportunity.

The interview with van den Berg and Scheffer adds new insights to this. They agreed that hydrogen is still expensive and that it is a result of the small scale and amount it is produced on. A lower hydrogen price is needed to improve the business case. They argued that the business case can only be completed when the number of customers the filling station will have is known. If this is unknown then even with subsidy it can be difficult to make a business case. There might be interest to become a customer but the concrete step to buying a vehicle can be slow (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). The lack of customers might be a sub barrier of the business case barrier because of the influence on completing the business case.

Schaap argued that because hydrogen is becoming more important in the wider economy, hopefully the production will scale up and the hydrogen price will drop. Then a more serious business case can be made. Furthermore, smaller initiators decide to save money on hiring project management or simply do not have the fund for this. The involvement of a project manager can speed up the implementation process significantly (D. Schaap, personal communication, May 1, 2020). The lack of funds for hiring a project manager can thus be seen as a barrier.

Finally, an opportunity that Horbach discussed is that the business case might be improved by offering multiple fuels besides hydrogen at a filling station location (R. Horbach, personal communication, April 28, 2020). The income from other fuels could then keep the filling station up and running until the hydrogen price becomes more viable.

All the sociotechnical system components that are researched can be related to this barrier. First of all, the structure component because the involvement of certain actors can improve the business case. Second the physical system because of the components that are expensive. Third, the tasks component because hydrogen and the components are not affordable and therefore one of the tasks is not completed.

The theory from Turnheim and Geels (2019) discussed early resource commitments as a large contributor to the success of a niche. The business case would be improved with those resource commitments. Therefore the business case barrier has made clear that it is indeed significant for hydrogen filling station implementation as well.

Permits and rules and regulation

One of the large barriers is related to the permits that are needed for a hydrogen filling station. Van der Meij mentioned that the permits can still be a problem (T. van der Meij, personal communication, April, 21, 2020) and Hemmerlin mentioned that the permitting process takes long, sometimes two years for a permit (F. Hemmerlin, personal communication, April 21, 2020). There is still some unfamiliarity of the actors that issue the permits with hydrogen. This is because most of them have not issued a permit for hydrogen before and that as a result there is no script for it (W. ter Veld, personal communication, April 23, 2020). Additionally,
Schaap also recognised that the actors who grant the permits have difficulties with Hydrogen. It is new to them, some might know it from industrial applications but that is mainly the case in large harbours. In most municipalities it is completely new, especially when applied to the built environment. It takes considerable extra research to get used to this new concept which results in a time delay during the permitting process. Furthermore, the people involved with the implementation of a filling station are different for every location as well. A different location means that a different municipality, different safety region and different people in general are involved. As a result, for every project new people run into the problem that hydrogen is new. An opportunity to solve this barrier would be to introduce more knowledge sharing (D. Schaap, personal communication, May 1, 2020). A sub barrier can thus be identified as hydrogen being unknown and new to people. The sharing of knowledge between actors could take away some of this unfamiliarity and thus shorten the permitting process. However, it might be impossible to completely remove the unfamiliarity with hydrogen. The component that is most related to this barrier is the structure component. The barrier comes from the interaction between the actors and the way the market works.

Related to the larger permit barrier is a sub barrier that was also discussed before in chapter 4, that can come from the municipal remediation policy. It is not a large barrier because usually the initiator is prepared and knows if it possible to build in a municipality. In some cities there are too many gas stations in the city itself. Therefore, the municipality can decide to not give out new permits for these gas station locations. Furthermore, when their maximum number of gas stations has been reached, they can decide to not give out a permit for a new gas station or in this case a hydrogen filling station. Without a permit, the filling station can not be built and a solution must be sought. This can sometimes be solved if the owner of a gas station has multiple locations and happens to also be the initiator of the hydrogen filling station (D. Schaap, personal communication, May 1, 2020). This is mainly a structure barrier because it is up to municipal policy and the initiator to be prepared and choose a viable location.

Closely related to the permits barrier is a barrier regarding rules and regulation. It goes into more detail on the rules and legislation that are involved at hydrogen filling station implementation. As van der Meij mentioned, a lot of the legislation has not been adapted yet to hydrogen being used on many places in the normal society besides having been used in the industry for decades. There is already a large amount of experience with safety legislation for hydrogen in the industry but that is a different setting that normal society where civilians and public space are involved. In many cases the legislation is not adapted to this different situation yet. This asks for the use of common sense and using the legislation that is most similar (natural gas). Pilot projects can be used as an opportunity to adapt this legislation (T. van der Meij, personal communication, April, 21, 2020).

An opportunity that Hemmerlin mentioned is that we need more and faster transfer of knowledge and experience. When one municipality has learned from the problems with rules and regulation, that knowledge must be transferred to other municipalities (F. Hemmerlin, personal communication, April 21, 2020). This is the same opportunity that was also introduced for the permit barrier. Therefore, it seems to be one of the most important opportunities. This barrier is once more related to the structure component because of the relation to the interplay of actors and market structure.

The theory by Schot and Geels (2008) who identified building social networks and learning processes as important influences on the successfulness of regime change seems applicable to this barrier as well as the permit barrier. The actors are involved in learning processes because it is a new theme for them. Perhaps they can use the social networks that are created to communicate the outcomes of the learning process, resulting in knowledge sharing.

Lastly, there arguably is another sub barrier that can be identified as the underestimation of hydrogen. A hydrogen filling station is not a normal gas station and it is more complicated for construction, legislation, permits and the land use plan. Perhaps the legislation or permits are not the problem but instead the underestimation of the consequences is. Most of the filling station projects that have been completed did have a delay and thus took longer than expected. This is partially due to the legislation and due to it being something new in a region, complicating the permission process. Furthermore, because it is unknown to citizens as well there is a larger chance of citizens objecting to it, which also takes extra time. The underestimation of these implications can therefore arguably be seen as the barrier (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). This barrier is also related to the structure component because underestimation is something the actors do.

Technological barriers

A barrier can come from the technological part of the filling station. Because the technological equipment is new there might still be teething problems that have to be overcome. Sometimes the equipment is not good enough yet and does not function. This can cause a delay in the construction because these problems must be solved. The opportunity related to this is one of the reasons why subsidy is provided to these filling station. When these barriers can be overcome with subsidized money, that will make the process better in the long run, when it is left to the market. Resulting in a smaller risk of the barrier remaining and limiting the filling station implementation (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). Furthermore, sometimes the filling stations do not work while there is still a low number of them available. As a result, a customer might have to drive a considerable distance to the next filling station (D. Schaap, personal communication, May 1, 2020). This is inconvenient and a better coverage would be needed to provide more security for the users. This barrier can clearly be related to the physical system component of the sociotechnical system because it comes from the technological components. It also shows some relation to the tasks component because the filling station can not perform its tasks if the technology does not work.

Structure, guidance or stable long-term vision

The importance of structure and guidance from the national government is something that is often mentioned by the interviewees. It has also been mentioned in the theoretical framework by Schot and Geels (2008) and Turnheim and Geels (2019). Both studies discussed the importance of structure and guidance in transition. Therefore, it was expected that this barrier would come up and was deemed important by the respondents.

When asked about the importance of structure and guidance from the government, Ter Veld mentioned that there is better structure and guidance than five years ago but it can always be improved (W. ter Veld, personal communication, April 23, 2020). The importance of structure was explained by Hazenberg. From the point of view of a transportation company structure is needed because their investments are large and the trucks they buy will be used for 7 years. They need the security that there will be a filling station when they buy these trucks. They do not want to have the vehicles waiting for a filling station (W. Hazenberg, personal communication, April 21, 2020).

Van der Meij also underscored the importance of structure through a strategic vision from the government. Security is needed that this vision does not change because a large number of investments must be made. The hydrogen vision of the Dutch government just came out at the time of this interview and is a good addition to this structure. This could also help to overcome the barrier that is a lack of integration of hydrogen with for example an energy- or heating vision (T. van der Meij, personal communication, April, 21, 2020).

The ministry was also interviewed on this subject and mentioned that the national vision is on hydrogen is currently being converted to policy (D. Schaap, personal communication, May 1, 2020). Perhaps that a lot of the structure and guidance from the government is still being worked on right now. Thus, the situation will likely change soon but it might take some time before this trickles down to all the involved actors. Some more info is provided at the additional opportunities. The sociotechnical system component that is the most related to this barrier is the structure component.

Transportation barriers

There are several barriers related to the transportation of hydrogen from the production facility towards the hydrogen filling station. Some of these have already been identified in section 5.1 such as the need for keeping the delivery of hydrogen separated from the filling of cars as mentioned by van der Meij for example (T. van der Meij, personal communication, April, 21, 2020).

One barrier comes from the tube trailers that are currently used which cause problems. A tube trailer can transport approximately 300kg of hydrogen at a time. When a hydrogen filling station needs to be supplied that could cause traffic jams of tube trailers at filling stations waiting to supply their hydrogen. Hydrogen transportation with tube trailers is therefore not seen as a long-term solution (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). A more long-term solution, and thus an opportunity would be a hydrogen pipeline or even a network of pipelines such as the backbone that was mentioned earlier in this research.

A pipeline would also significantly reduce the cost of transporting hydrogen (W. Hazenberg, personal communication, April 21, 2020). This could also reduce the hydrogen price itself as a result.

Schaap mentioned that to reach the goals set in the climate agreement for 2030 (300.000 hydrogen vehicles) and 300-400 filling stations are needed. That means that if all those filling stations need hydrogen deliveries with tube-trailers 2,5 times a day 2000 truck movements to and from those filling stations would have to be made. This is simply not possible due to safety legislation for the road network (D. Schaap, personal communication, May 1, 2020).

Besides the hydrogen backbone as an opportunity there is another possibility that was mentioned by Schaap. That would be producing hydrogen at multiple production locations so that you only need short pipelines to your filling stations and no tube trailers (D. Schaap, personal communication, May 1, 2020). This brings us to the next barrier which comes from production of hydrogen. The transportation barriers are related to the physical system and task components.

Production barrier

One barrier comes from a lack of hydrogen production capacity in the Netherlands and especially for green hydrogen. This was illustrated by van de Watering in the interview. The goal is to produce hydrogen from green energy. If we do not produce enough green energy (that is also used directly for electricity) then we can not make enough green hydrogen (F. van de Watering, personal communication, April 29, 2020).

An opportunity that has been discussed by several respondents is producing hydrogen in the Sahara Desert and then transporting it to the Netherlands (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). There is an abundance of sunlight there that could potentially provide a large amount of green energy. This barrier comes from the physical system component.

Public support or resistance

As was also discussed in chapter 5.1 at the society section, public support has an influence on hydrogen filling station implementation. The municipality has a large responsibility for the implementation of a filling station. It could be difficult to implement it into their land use plan (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). The municipality is also responsible for its citizens and needs public support, a lack of this public support can form aa barrier.

That means that not only the technical side of building a filling station must be in order but also the environment must not be forgotten. The involved citizens should be informed to prevent resistance from them. An opportunity related to this is making the hydrogen vehicles more visible for people in their daily life (T. van der Meij, personal communication, April, 21, 2020).

Additionally, citizens can resist or object to the plans for a filling station. If an objection (zienswijze in Dutch) is made by civilians the permission term gets extended by quite some time. Because the relevant actor is given a 6-week time period to react to it (D. Schaap, personal communication, May 1, 2020). This can lengthen the implementation process considerably and therefore it must be prevented as much as possible. The most likely solution for this might be the informing or involving the citizens (as discussed in 5.1).

Lack of vehicles

The lack of vehicles that are available or operational is a barrier for filling station implementation.

The interview with van den Berg and Scheffer discussed the example of Germany where there are approximately 80 filling stations but still a small number of hydrogen vehicles available.

The opportunity they identified is that when planning new filling stations then coordination and clear communication by the government with vehicle manufacturers might be needed (N. van den Berg & S. Scheffer, personal communication, May 8, 2020).

Schaap agrees that there is a lack of available vehicles. The ministry does subsidize some vehicles such as garbage trucks because they are visible applications of hydrogen (D. Schaap, personal communication, May 1, 2020). Perhaps an opportunity is that they can do this more often. Because apparently this part of the problem is still substantial it is a part of the lock-in situation.

Hemmerlin seems to support this opportunity by suggesting a stable long-term policy that is aimed at supporting clean cars. This would be based on making sure that clean vehicles are more affordable than polluting vehicles. It would need to be different than the subsidy for BEVs in the Netherlands right now where the subsidy is removed quickly while BEVs are only a small portion of all the cars in the Netherlands now (F. Hemmerlin, personal communication, April 21, 2020).

Ter Veld suggests that maybe from a European level an increase in vehicles could be initiated. The goal would be to lower the price and increase the demand for hydrogen from mobility, especially for heavy transport (W. ter Veld, personal communication, April 23, 2020).

This barrier seems to be related to the fourth sociotechnical system component of people. However, it does not go into detail on the people but mainly on the actor that is a vehicle manufacturer (thus the structure component).

Protected animal species

A small barrier comes from protected species. Sometimes, as with many projects, protected animal species can be a barrier. This can create a lot of additional requirements and therefore the plans for the construction of a filling station might be cancelled. This has happened with two filling stations in the Netherlands so far (D. Schaap, personal communication, May 1, 2020). This external barrier can not really be connected to one of the components but it is important to keep in mind.

5.2.2 Additional Opportunities

Additional opportunities were identified during the interviews that were deemed important to discuss on their own and are related to the role of the government.

The role of the government

The first opportunity is regarding the role of the government. Perhaps the government can rethink its role in the transition and in hydrogen filling station implementation. This has been mentioned in chapter 4 as well. These opportunities are all related to the structure component.

Right now, the government leaves the filling station implementation to the market. Perhaps through concessions the government can play a more active role and steer more. The ministry is thinking about their role in demand gathering and in location choice. But in the end the entrepreneurs must make the choice for hydrogen themselves (D. Schaap, personal communication, May 1, 2020).

Taking the lead could be help with convincing actors who would prefer continuing their old path while switching to hydrogen could be a good decision for them. Or for actors that see hydrogen as a threat (W. ter Veld, personal communication, April 23, 2020).

Expanding upon this role of the government Rijkswaterstaat might have an opportunity as well. Rijkswaterstaat is responsible for the rest areas along the highways. Currently they are discussing what these rest areas will look like in the future. For example, incorporating quick charging facilities for BEVs or facilities for other fuels. This goes hand in hand with the 'benzinewet' (gasoline law) that is changing in 2024. An aspect that also has to be decided upon is how the concessions are handled in the future, or if they hypothetically become auctions or something else (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). There are opportunities in this change to incorporate hydrogen filling stations.

Using these concessions is what the ministry eventually aims at. When an actor gets the concession, he would have to offer alternative fuels as requested in the concession. That does not have to be done straight away from the opening of the gas station but perhaps after a number (3-5) of years. However, it must be emphasized that this is still speculation and not a definitive plan or policy (D. Schaap, personal communication, May 1, 2020).

Hemmerlin sees an opportunity to change the way subsidy is handled. The subsidy should not be aimed at innovation but should be aimed at building the network of filling stations. He suggests giving subsidy on the number of kilograms of hydrogen that are sold and hypothetically give the hydrogen for free. In that way actually driving the vehicles is stimulated by letting cars, trucks or garbage trucks drive for free for example. With this subsidy the reward of being sustainable would be felt and seen directly by the users. A customer would pay at the filling station and receives the money back on their bank account within a few days. This would mean that the government only spends money on subsidizing the actual hydrogen directly. Additionally, a car manufacturer who sells polluting cars then could be made to pay extra taxes which could then be used for the subsidy on hydrogen. Then the one polluter pays for the clean vehicle users (F. Hemmerlin, personal communication, April 21, 2020).

This opportunity or potential solution would solve the hydrogen price problem and could help with the business case. It would make hydrogen more attractive and therefore improve the business case another time by an increase in customers.

An opportunity that was discussed by Hazenberg is a CO2 ladder. When the government gives out a tender, they can give a discount to companies that are sustainable (have sustainable vehicles on hydrogen for example). So according to your level on the CO2 ladder you get for example a 2% discount. Because of a validated rating, you are more attractive in the tender than a company with a lower level on the CO2 ladder, even though you offer the same price. This is a way that does not really cost money (only virtually) but does stimulate sustainable behaviour (W. Hazenberg, personal communication, April 21, 2020).

A province (the regional government) also has opportunities from their role as a government. They could bring together all the municipalities on hydrogen through a regional hydrogen covenant. Furthermore, some provinces hold the concession for public transport and can influence the vehicle type of public transport through that (R. Horbach, personal communication, April 28, 2020).

Smart grid

In chapter 4 the smart grid was identified as an opportunity or possible alternative for hydrogen filling stations. However, most respondents did not agree with the theory and did not see it as a viable option. Ter Veld argued that smart grid is not an option because the components work better at large scale (W. ter Veld, personal communication, April 23, 2020). Regarding safety it was also deemed not viable and it would be too expensive (N. van den Berg & S. Scheffer, personal communication, May 8, 2020). Van der Meij agreed that a smart grid solution would not be likely for one household, but she suggested for a village or neighbourhood or in combination with farmers you could create a neighbourhood fuel cell or filling station. A local energy network could be complemented with hydrogen production and filling station but that would need hiring of experts (T. van der Meij, personal communication, April, 21, 2020). All in all, it can be said that production of hydrogen at home was not expected to have much potential in the short term.

6 Conclusion & Reflection

This research investigated the implementation of hydrogen filling stations in the context of the hydrogen mobility transition. Qualitative methods were used with an exploratory approach, through desk research and nine expert interviews with people from different background and companies. The hydrogen filling station implementation was researched with a sociotechnical systems approach from which the physical system, task and structure component were researched in chapter 4. This chapter added the basis from which the barriers and opportunities were identified. These barriers and opportunities were identified and analysed in chapter 5. This has resulted in a comprehensive understanding of hydrogen filling station implementation and how it can be improved upon. It also provided insight regarding the position of hydrogen filling station implementation within the hydrogen transition.

This final chapter focuses on the conclusions of the research and reflects on the research process. First the sub questions will be answered in order to answer the main question: *What barriers and opportunities that limit or improve hydrogen filling station implementation can be identified in its sociotechnical system within the hydrogen mobility transition in the Netherlands?* Subsequently, the research is reflected upon after which research recommendations are made.

6.1 Conclusion

Sub question 1: *What role does the physical system play in the implementation of hydrogen filling stations in the Netherlands?*

The physical system component was researched in chapter 4.3 by looking at the technological side. A distinction was made between the energy system and hydrogen filling stations themselves. For the energy system the choice for production process and which energy source is used for production were discussed as well as the transportation method. An important finding was that these influence the hydrogen price and availability of hydrogen that are important for hydrogen filling station implementation because without hydrogen a filling station is useless. Furthermore, the distinction between a centralized (on-site) or decentralized (off-site) model was found. As it turned out, the production location influences the transportation of hydrogen to the filling station and therefore also the construction and hydrogen costs. The hydrogen filling stations themselves differ in size and whether they only offer hydrogen or multiple fuels. Furthermore, eight technological components of the filling station were identified. These are (1) production (and transportation), (2) purification system (important for when pipelines are used), (3) low pressure storage, (4) hydrogen compressor (that compresses to 350 or 700 bars), (5) high pressure storage, (6) hydrogen gas booster, (7) hydrogen cooler system and (8) hydrogen dispenser. These components have a large technological complexity. Lastly, the opportunity for a smart grid was identified.

The most important finding is that the physical system component can complicate the implementation through technological complexity and the choices made that were reflected in the categorizations. It can be concluded that the physical system component plays an important role in filling station implementation.

Sub question 2: *What role does the task component of sociotechnical systems play in the implementation of hydrogen filling stations in the Netherlands?*

The role of the task component was identified in chapter 4.4 and based on two approaches. First, the tasks were identified from the four factors that have been identified in the theoretical framework: the economic, safety, location and social factors. Additionally, a number of tasks were identified from the definition of sustainability. These are ease and practical usability, convenience (shop or workplace, affordability (price) and accessibility (location). The most important finding is that the influence of the task component on hydrogen filling station implementation thus comes from not meeting these tasks, which can result in barriers and became apparent at sub question 4.

Sub question 3: *What role do structure and relevant actors play in the implementation of hydrogen filling stations in the Netherlands?*

The structure component was researched in chapter 4.5 by identifying and analysing the actors, their roles and the market structure. The roles the actors play have a large influence on implementation process and can cause barriers. These have effects on the length of the process and eventually on the transition. The actors were categorized by their sector (state, market, community and non-profit) as identified by Avelino and Wittmayer (2016). First of all, the large influence of the initiator became apparent because the initiator links all the other actors together. Furthermore, the subsidy and permits turned out to be the most distinct tools. Based on Mitchells, Agle and Wood (1997) the actors were analysed further by determining their power, legitimacy and urgency. Some actors such as vehicle manufacturers do not feel the urgency of a hydrogen mobility transition. Other actors feel the urgency, such as the initiator, but do not have enough power to create this transition on their own. State actors have large power, legitimacy and a varying sense of urgency. From this analysis the most important finding is that the state actors in the form of the government have the best conditions to make a change and should take the lead. Concludingly, the structure and actors play a large role because they determine the process itself. They are of varying importance and can facilitate improvement to hydrogen filling station implementation.

Sub question 4: *What are the opportunities and barriers regarding the implementation of hydrogen filling stations in the Netherlands?*

The three components work together in the sociotechnical system and result in opportunities and barriers. In chapter 5, this fourth sub question was answered by distinguishing the opportunities and barriers for the implementation of hydrogen filling stations. First the findings regarding the factors as a source of barriers and opportunities were discussed. The economic factor is an important source of barriers. The safety factor is not a big source of barriers. The optimal locations for hydrogen filling stations would be places that are near logistical hotspots, highways and near a future pipeline or backbone. The location factor is not a large influence on the barriers. The society factor shows the importance of public support and informing citizens and that it can be a source for barriers. The spatial effects are limited to mainly the large footprint as a result of safety distances.

The first most important barrier is the current impossibility of creating a business case. The related opportunity is lowering the hydrogen price through a larger importance of hydrogen in the industry and offering multiple fuels at a hydrogen filling station. The second barrier is difficulty and time delays that come from permits and legislation (from unfamiliarity with the new hydrogen), which are large barriers. An increase in the transfer of knowledge is a good opportunity and solution to solve these barriers. Underestimation might be the underlying problem. Sometimes the technological components are not good enough or do not function.

This can be overcome by continuing to develop these. Structure and guidance in the form of a stable vision from the government is needed and the lack of it forms a barrier. This will be solved when new policy comes available. Currently hydrogen is transported with trucks but this is not viable for the long term. Pipelines are more viable because they are more affordable and have a larger capacity. Another barrier is that there is not enough (green) hydrogen production, the opportunity is importing green hydrogen, for example from the Sahara Desert. Public support needs to be there for a filling station, the opportunity is to inform the public. Lastly, there is a lack of hydrogen vehicles for which the opportunities for more and different subsidy, perhaps also from European level, exist.

Additional opportunities were identified that can improve hydrogen filling station implementation. The main focus was on the role of the government. The government should take a more leading role and can do this by subsidizing hydrogen directly, handling concessions differently for the filling stations, or regarding concessions in general, giving advantages to companies that are green.

Concludingly, a large number of barriers and opportunities have been identified that greatly influence hydrogen filling station implementation.

Main question

With the answers of the four sub questions the main question can now be answered. The main question is: *What barriers and opportunities that limit or improve hydrogen filling station implementation can be identified in its sociotechnical system within the hydrogen mobility transition in the Netherlands?*

The three components of the sociotechnical system were described and it is clear that they cause barriers. The barriers were described when answering sub question four. The most important barriers are the business case, permits and legislation (unfamiliarity) and lack of vehicles. Fixing these barriers and making the most of the opportunities improves hydrogen filling station implementation. Furthermore, as was already mentioned, the larger hydrogen mobility transition forms the context of this research. As a result of an improved hydrogen filling station implementation the hydrogen mobility transition can also be improved. Most importantly, the focus should be more on lowering the price of hydrogen itself and solving the lack of vehicles (the vehicle side of the lock-in situation) with subsidy from the government. Because without these the hydrogen filling station business case can not be completed and the lock-in situation will not be solved.

From these barriers and opportunities, it can be concluded that hydrogen filling stations and mobility can not be seen without the larger transition. The hydrogen price is perhaps the largest underlying barrier. Measures that have effect on the hydrogen price are important and can also come from other sectors in the larger hydrogen transition. This arguably proves that a comprehensive approach towards a larger hydrogen transition is needed.

6.2 Reflection on the research process

Regarding the interviews an improvement could have been made on the number of interviews held. Having more respondents is always better but due to time limitations this was not possible. Perhaps more interviews could have been done with other actors such as car manufacturers, Bovag or RAI. Some of these companies were contacted but did not want to cooperate, responded late or did not respond at all. A late response meant that there was no time left to incorporate the interview into the research within the set timeframe. The number of respondents was sufficient for this research (enough data was gathered) and therefore it is assumed that this did not have a large influence on the results. This was also confirmed by the fact that a point of saturation regarding the data was reached. No really new data was being found and most of the data was similar to that of previous interviews.

Expanding more on the respondents that were involved in this research, it can be said that the hydrogen filling station world in the Netherlands is still a relatively small sector. This might have influenced my research because one respondent can have a relatively large influence on the research. Furthermore, if said respondent has been involved with one case then that one case can already have a large influence on the research. This is due to the small number of filling stations that have been built. However, because the respondents had worked on different cases this effect has probably been limited for this research. The lessons learned from the limited number of filling stations that have been implemented or are being implemented are still very valuable.

The influence of the researcher himself should not be underestimated. With a qualitative method as used in this research the personal interpretation influences the results. The interview questions are always subject to interpretation by the researcher and the respondent. Even though it was attempted to be as objective as possible, it is not possible to be completely objective. Because this fact was determined beforehand, this has not had a large influence on the research outcomes.

There were a few small setbacks during the research that resulted in more time being necessary. Firstly, transcribing the interviews took more time than expected. Transcribing turned out to be a very time-consuming process. This was mainly due to the number of interviews, the length of the interviews (nearly one hour each) and bad recording quality and partially due to inexperience with this process.

After the interviews were held, some recalibration of the research was needed. It meant that some extra time was needed to complete the research, but it also helped improve the research considerably. The recalibration meant that the research questions were updated and the scope of the theoretical framework was adjusted. Also, the structure for the chapters was changed. The sociotechnical systems approach was made more important throughout the research. Perhaps if this approach were already used before the interviews were held, more direct questions about the sociotechnical system could have been asked. This could have made the research process easier and would have given more direct data on the components but the data that was available was sufficient to answer the research questions.

The recalibration also meant that some interview questions lost some of their relevance for the research and were therefore partially left out but were mainly integrated in other sections. For example, the future vision of the respondents was an important separate part of the research initially but has now for the most part been integrated into the barriers and opportunities.

New innovations in the field of hydrogen make it sometimes difficult to stay up to date and when giving data on certain things this must be kept into account. New information on the subject comes up frequently, as a result it is difficult or arguably even impossible to keep providing the most actual information. From the point of view of the hydrogen transition that is a good development. It means that the transition is coming up to speed and it is being put on the agenda.

The option to replace the opportunities and barriers approach and introduce a SWOT analysis in chapter 5 was considered. Maybe a SWOT would have been more complete than just opportunities and barriers. However, for this exploratory research the opportunities and barriers were deemed sufficient. Furthermore, no distinction was made between external and internal influences from the beginning of the research. It might have been difficult to apply this to an implementation process.

The academic relevance of this research should also be reflected upon. This research confirms that a sociotechnical systems approach can give new insights into hydrogen filling stations and probably also in other comparable subjects. It turned out to be a useful way of making a comprehensive exploratory analysis of a complex problem. In this research the structure component was approached in a slightly different way than described in theory. This way of looking at structure from an actor and market structure perspective is something that could be added to the theory.

Lastly, looking back at the conceptual model, this model captured the essence of the subject well no changes have to be made. However, further research might change or expand on the model.

6.3 Further research

There are a number of recommendations for further research. First, complementary to this research is further research that focuses on the fourth component of the sociotechnical system. It was left out of the scope for this research but would be valuable as well. The end users are a large group of people and their opinions and preferences should be considered.

Second, further research should focus more on the vehicle side of the lock in situation. In this research it was identified that this side has opportunities for improvements and these could be the subject of research. Research focused on the preferences of possible users could be useful to identify how they can be motivated to buy hydrogen vehicles, for example. Additionally, research on how the government can motivate these users can also be valuable.

Third, an international comparison of the implementation process and the hydrogen transition between the Netherlands and other countries should be made. The insights from other countries can be useful to identify and overcome barriers that have already been overcome in these other countries. Together these further research opportunities could potentially contribute to an improved hydrogen transition.

Lastly, the greater hydrogen mobility transition and the entire hydrogen transition including heating and other applications deserves more research. Perhaps similar studies as this research, using a sociotechnical systems approach, can be done for other subjects regarding hydrogen. The advantage would be that these are comparable to this research and additional barriers and opportunities could be identified.

Appendix

The following appendices are attached:
A. References
B. List of interviews
C. Interview questions
D. Codebook

Appendix A - References

AD (2019). Waterstoftaxi's kondigen nieuw tijdperk aan. [News item]. Accessed on: 25-06-2020. Retrieved from: https://www.ad.nl/auto/35-waterstoftaxi-s-kondigen-nieuw-tijdperk-aan~ae7542e0/

Alavi, F., Lee, E. P., van de Wouw, N., De Schutter, B., & Lukszo, Z. (2017). Fuel cell cars in a microgrid for synergies between hydrogen and electricity networks. *Applied Energy*, *192*, 296-304.

Apostolou, D., & Xydis, G. (2019). A literature review on hydrogen refuelling stations and infrastructure. Current status and future prospects. *Renewable and Sustainable Energy Reviews*, 113, 109292.

Auvinen, H., & Tuominen, A. (2014). Future transport systems: long-term visions and socio-technical transitions. *European Transport Research Review*, *6*(3), 343-354.

Avelino, F., & Wittmayer, J. M. (2016). Shifting power relations in sustainability transitions: a multi-actor perspective. *Journal of Environmental Policy & Planning*, *18*(5), 628-649.

Baarda, B., Bakker, E., Fischer, T., Julsing, M., Peters, V., van der Velden, T., & de Goede, M. (2013). *Basisboek kwalitatief onderzoek: Handleiding voor het opzetten en uitvoeren van kwalitatief onderzoek*. Noordhoff Uitgevers, Houten/Groningen.

Backhaus & Bunzeck (2010). *Planning and permitting procedures for hydrogen refuelling stations: analysis of expected lead times for hydrogen infrastructure build-up in the Netherlands*. ECN-E--10-051, ECN, Amsterdam.

Bansal, P. (2015). Charging of electric vehicles: technology and policy implications. *Journal of Science Policy & Governance*, *6*(1), 1-20.

Bider, I., & Klyukina, V. (2018). Using a socio-technical systems approach for a sales process improvement. In *2018 IEEE 22nd International Enterprise Distributed Object Computing Workshop (EDOCW)* (pp. 48-58). IEEE.

Bonges, H. A., & Lusk, A. C. (2016). Addressing electric vehicle (EV) sales and range anxiety through parking layout, policy and regulation. *Transportation Research Part A: Policy and Practice*, *83*, 63-73.

Brey, J. J., Carazo, A. F., & Brey, R. (2018). Exploring the marketability of fuel cell electric vehicles in terms of infrastructure and hydrogen costs in Spain. *Renewable and Sustainable Energy Reviews*, *82*, 2893-2899.

CROW (2008). Krachtenveldanalyse. [Webpage]. Accessed on: 9-3-2020. Retrieved from: https://www.crow.nl/downloads/documents/kpvv-kennisdocumenten/krachtenveldanalyse

CROW (n.d.) Krachtenveldanalyse. [Webpage]. Accessed on: 9-3-2020. Retrieved from: https://www.crow.nl/kennis/bibliotheek-verkeer-en-vervoer/kennisdocumenten/krachtenveldanalyse

Docherty, I., Marsden, G., & Anable, J. (2018). The governance of smart mobility. *Transportation Research Part A: Policy and Practice*, *115*, 114-125.

European Commission (n.d.). Paris agreement. [Webpage]. Accessed on: 11-3-2020. Retrieved from: https://ec.europa.eu/clima/policies/international/negotiations/paris_en

Fuelcellsworks (2020). New hydrogen station opened in the Hague. [News item]. Accessed on: 25-06-2020. Retrieved from: https://fuelcellsworks.com/news/new-hydrogen-station-opened-in-the-hague/

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research policy*, *33*(6-7), 897-920.

Green Planet, (n.d.). Green Planet waterstof. Accessed on: 25-06-2020. Retrieved from: https://greenplanet.nl/brandstoffen/waterstof/

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. *Handbook of qualitative research, 2* (163-194), 105.

H2platform (2019). Vanaf 2020 waterstof tanken in Amsterdam. [Webpage]. Accessed on: 26-05-2020. Retrieved from: https://opwegmetwaterstof.nl/vanaf-2020-waterstof-tanken-in-amsterdam/

H2Platform (2020). Hoeveel waterstofauto's zijn er in Nederland? Accessed on: 14-05-2020. Retrieved from: https://opwegmetwaterstof.nl/2019/02/18/hoeveel-waterstofautos-er-nederland/

H2Platform (n.d., a). Waterstof tanklocaties. [Webpage/map]. Accessed on: 22-06-2020. Retrieved from: https://opwegmetwaterstof.nl/tanklocaties/

H2Platform (n.d., b). Waterstof tanken komt eraan! [Webpage]. Accessed on: 24-06-2020. Retrieved from: https://opwegmetwaterstof.nl/h2tanken/

Holthausen (2020). Duurzaam Rijden in Nederland. [Webpage]. Accessed on: 26-05-2020. Retrieved from: https://www.holthausen.nl/clean-energy-solutions/holthausen-energy-points

Honselaar, M., Pasaoglu, G., & Martens, A. (2018). Hydrogen refuelling stations in the Netherlands: An intercomparison of quantitative risk assessments used for permitting. *International journal of hydrogen energy*, *43*(27), 12278-12294.

Huygen, A., Maas, N., Djafari, S., Woestenburg, A., Laarakkers, J., & Smokers, R. (2018). *Publieke Laadinfrastructuur Elektrisch Vervoer en rol van MRA-E en G4* (No. TNO 2018 R10769). TNO.

Huijts, N., de Vries, G., & Molin, E. J. (2019). A positive shift in the public acceptability of a low-carbon energy project after implementation: The case of a hydrogen fuel station. *Sustainability, 11*(8), 2220.

Huijts, N. M. A., & Van Wee, B. (2015). The evaluation of hydrogen fuel stations by citizens: The interrelated effects of socio-demographic, spatial and psychological variables. *International Journal of Hydrogen Energy*, *40*(33), 10367-10381.

Itaoka, K., Saito, A., & Sasaki, K. (2017). Public perception on hydrogen infrastructure in Japan: Influence of rollout of commercial fuel cell vehicles. *International Journal of Hydrogen Energy*, *42*(11), 7290-7296.

Kennisinstituut mobiliteit (2017). Mobiliteitsbeeld 2017. [Research report]. Retrieved from: https://www.kimnet.nl/mobiliteitsbeeld/mobiliteitsbeeld-2017

Lahnaoui, A., Wulf, C., Heinrichs, H., & Dalmazzone, D. (2019). Optimizing hydrogen transportation system for mobility via compressed hydrogen trucks. *International Journal of Hydrogen Energy*, *44*(35), 19302-19312.

Lam, D. and Head, P. (2012). Sustainable Urban Mobility. In Inderwildi, O. and King, D. (Eds.) *Energy, Transport, & the Environment*, 359-371, Springer-Verlag, London.

Lipman, T. E., Elke, M., & Lidicker, J. (2018). Hydrogen fuel cell electric vehicle performance and user-response assessment: Results of an extended driver study. *International Journal of Hydrogen Energy*, *43*(27), 12442-12454.

Lupton, D. (2020). Doing fieldwork in a pandemic. [Crowd-sourced document]. Accessed on: 08-04-2020. Retrieved from: https://docs.google.com/document/d/1clGjGABB2h2qbduTgfqribHmog9B6P0NvMgVuiHZCl8/edit?ts=5e88ae0a#

Lyons, G. (2018). Getting smart about urban mobility–aligning the paradigms of smart and sustainable. *Transportation Research Part A: Policy and Practice*, *115*, 4-14.

Matinaro, V., & Liu, Y. (2015). Virtual design and construction: innovation process and diffusion in Finnish construction business. *International Journal of Innovation and Learning*, *18*(2), 133-150.

Matthijsen, A. J. C. M., & Kooi, E. S. (2006). Safety distances for hydrogen filling stations. *Fuel cells bulletin*, *2016*(11), 12-16.

Mitchell, R. K., Agle, B. R., & Wood, D. J. (1997). Toward a theory of stakeholder identification and salience: Defining the principle of who and what really counts. *Academy of management review*, *22*(4), 853-886.

Moore, R. B., & Raman, V. (1998). Hydrogen infrastructure for fuel cell transportation. *International Journal of Hydrogen Energy*, *23*(7), 617-620.

Needham B. (2006). Planning, law and economics. The rules we make for using land. London: Routledge.

NOS (2019). Elektrische auto meest verkochte model, is dit de doorbraak? [News item]. Accessed on 24-09-2019. Retrieved from: https://nos.nl/artikel/2304686-elektrische-auto-meest-verkochte-model-is-dit-de-doorbraak.html

NOS (2020). Elektrische auto in 2019 voor het eerst het populairst. [News item]. Accessed on 4-3-2020. Retrieved from: https://nos.nl/artikel/2316976-elektrische-auto-in-2019-voor-het-eerst-het-populairst.html

Offer, G. J., Howey, D., Contestabile, M., Clague, R., & Brandon, N. P. (2010). Comparative analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system. *Energy policy*, *38*(1), 24-29.

Oosthuizen, R., & Pretorius, L. (2016). Assessing the impact of new technology on complex sociotechnical systems. *South African Journal of Industrial Engineering*, *27*(2), 15-29.

Resato (n.d.). Waterstof technologie. [Webpage]. Accessed on: 24-06-2020. Retrieved from: https://www.resato.com/nl/waterstof

Robinius, M., Linßen, J., Grube, T., Reuß, M., Stenzel, P., Syranidis, K., Kuckertz, P. & Stolten, D. (2018). Comparative analysis of infrastructures: hydrogen fueling and electric charging of vehicles. *Forschungszentrum Jülich: Jülich, Germany*.

RVO (n.d.). H2-tankpunt Green Planet Pesse. [Webpage]. Accessed on: 25-06-2020. Retrieved from: https://www.rvo.nl/initiatieven/dkti-tenders/h2-tankpunt-green-planet-pesse

RWS Duurzame Mobiliteit (n.d.). Rijden op waterstof. Accessed on: 14-05-2020. Retrieved from: https://rwsduurzamemobiliteit.nl/praktijk-projecten/tank/rijden-waterstof/

Scheepers, P., Tobi, H. & Boeije, H. (2016). *Onderzoeksmethoden*. Amsterdam: Boom.

Schot, J., & Geels, F. W. (2008). Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology analysis & strategic management*, *20*(5), 537-554.

Smit, R., Weeda, M., & De Groot, A. (2007). Hydrogen infrastructure development in The Netherlands. *International Journal of Hydrogen Energy*, *32*(10-11), 1387-1395.

Steurer, R. (2013). Disentangling governance: a synoptic view of regulation by government, business and civil society. *Policy Sciences*, *46*(4), 387-410.

TNO (n.d.). Tien dingen die je moet weten over waterstof. [Webpage]. Accessed on: 23-06-2020. Retrieved from: https://www.tno.nl/nl/aandachtsgebieden/energietransitie/roadmaps/naar-co2-neutrale-brand-en-grondstoffen/waterstof-voor-een-duurzame-energievoorziening/tien-dingen-die-je-moet-weten-over-waterstof/

Turnheim, B., & Geels, F. W. (2019). Incumbent actors, guided search paths, and landmark projects in infra-system transitions: Re-thinking Strategic Niche Management with a case study of French tramway diffusion (1971–2016). *Research Policy*, *48*(6), 1412-1428.

Van Thiel, S. (2014). *Research methods in public administration and public management: An introduction.* Routledge.

Voermans, T. (2020, a). Vermogen elektrische laadpalen omlaag anders stad 'op zwart'. [News item]. Accessed on: 02-03-2020. Retrieved from: https://www.ad.nl/auto/vermogen-elektrische-laadpalen-omlaag-anders-stad-op-zwart~a1878199/

Voermans, T. (2020, b). Tesla's op wintersport in de laadpaalfile. [News item]. Accessed on: 02-03-2020. Retrieved from: https://www.ad.nl/auto/tesla-s-op-wintersport-in-de-laadpaalfile~a9da51e6/

Wang, Y. W., & Lin, C. C. (2009). Locating road-vehicle refuelling stations. *Transportation Research Part E: Logistics and Transportation Review*, *45*(5), 821-829.

Waterstof Net (n.d.). Overzicht waterstoftankstations Benelux. Accessed on: 23-10-2019. Retrieved from: https://www.waterstofnet.eu/nl/infrastructuur/overzicht-waterstoftankstations-benelux

Wilberforce, T., El-Hassan, Z., Khatib, F. N., Al Makky, A., Baroutaji, A., Carton, J. G., & Olabi, A. G. (2017). Developments of electric cars and fuel cell hydrogen electric cars. *International Journal of Hydrogen Energy*, *42*(40), 25695-25734.

Zimmer, R., & Welke, J. (2012). Let's go green with hydrogen! The general public's perspective. *international journal of hydrogen energy*, *37*(22), 17502-17508.