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Planning experimental hydrogen neighbourhoods

In the context of the Dutch energy transition

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Preface

Dear reader,

You are about to read my Master thesis which I wrote to graduate from my study Spatial Planning at Utrecht University. I also wrote my thesis for my internship at the industrial and environmental safety department of the National Institute for Public Health and the Environment (RIVM). I started writing this thesis in February. At that time using hydrogen in the energy transition was a natural gas alternative was fairly unknow to me. During the past five months I have learned a lot about the possibilities and vulnerabilities of using hydrogen as an alternative for natural gas in the built environment. I wrote this thesis during the COVID-19 pandemic, during a time the Netherlands was in lockdown, which influenced the process of writing my thesis. The willingness of everyone I interviewed for this thesis made it possible for me to write this thesis without many problems despite the pandemic restrictions. I want to thank everyone who I have interviewed for their contribution and suggestions. Furthermore, I want to give my special thanks to Jonas Torrens, my supervisor from Utrecht University, for his pleasant guidance and the constructing feedback. Finally, I want to thank Kyra Kieskamp, my internship supervisor from the RIVM, for all her guidance.

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Summary

The energy transition requires the search for alternatives for the use of fossil fuels in all sectors. The built environment is one of these sectors and in the Netherlands the built environment is largely heated by natural gas (Klimaatakkoord, 2019). Experimentation is fundamental for the Dutch approach to the energy transition in the built environment and experimentation is a way for planners to plan a future with emerging technologies (Programma Aardgasvrije Wijken, n.d.; Klimaatakkoord, 2019; Reimer, 2013; Scholl & de Kraker, 2021). At this point in time there are mainly three alternatives for the use of natural gas in the built environment, among which hydrogen as a sustainable gas (Expertise Centrum Warmte, 2020; Planbureau voor de leefomgeving, 2020). The possible transition towards using hydrogen in the built environment is largely dependent on the success of the two residential hydrogen experiments in Stad aan 't Haringvliet and Hoogeveen, as these experiments provide knowledge for policy and legislation (Nationaal Waterstof Programma, n.d.; Wiebes, 2020; Gigler, et al, 2020). However innovative experiments are likely to fail if they are not protected from constraining regime barriers (van den Heiligenberg, 2017; Kemp et al, 1998; Smith & Raven, 2012; Geels, 2019). Therefore this research examined how barriers and opportunities set by the socio-technical regime are experienced with the development of experimental hydrogen neighbourhoods in Stad aan 't Haringvliet and Hoogeveen.

Based on a literature review of transitions, innovations and hydrogen studies, the following theoretical constraining barriers could be identified. Technique & costs barriers, such as the extent to which the natural gas grid is adequate for the use of hydrogen and the costs of hydrogen (Detz et al, 2019; Dincer, 2012; Smith et al, 2007; Jempma & Schot, 2007; KIWA & Netbeheer Nederland, 2018). Safety barriers, based on the risk of using hydrogen as compared to the risks of natural gas and the related acceptance of risks (KIWA & Netbeheer Nederland, 2018; Kim & Moon, 2008; Gandia et al, 2013; Sherif et al, 2005; Najjar, 2013). Finally, policy & regulations can form a barrier when they are not adequate (Bakhuis , 2020; Detz et al, 2019).

Based on the literature review interviews were conducted with experts, niche actors in the experiments, regime actors outside of the experiment and intermediate actors. The interview data was combined with policy documents and based on that four key themes, that provide barriers and opportunities for the success and upscale possibilities of the experiments, could be identified. The first theme is the rational for experimentation and the comprehensiveness of the experiments. The experiment in Stad aan 't Haringvliet has a more natural rational for selecting hydrogen as natural gas alternative and is more comprehensive in terms of building types. The experiment in Hoogeveen has a more strategic rationale for selecting hydrogen and is less comprehensive in terms of building types. This difference could influence the extent to which the experiments differ in success. The second theme is the possibility of using the natural gas grid for hydrogen, which would give the use of hydrogen advantages over other natural gas alternatives. However there are technical, regulatory and financial uncertainties to this which the experiments are not addressing and could hinder their success. The third theme addresses the issue of the safety of using a new hazardous substance in the built environment. The main constraining barriers here are the acceptance of the risks involved by the residents and the government and the incorporation of hydrogen in the safety system and are addressed by the experiments. However residential risk acceptance remains an uncertain factor. The final theme considers the protection of the experiments. The protection of the experiments is fragile and not consciously addressed by the experiments which could hinder their success.

Conclusively, this thesis shows that the experiments are not addressing all opportunities and barriers because stakeholders in the experiments are not aware of these barriers and opportunities and because the focus of the experiments is on realizing a hydrogen neighborhood which diverts attention from other issues. To upscale the use of hydrogen it is important that the experiments

address the constraining barriers and planners are informed of the use of hydrogen. If planners are unaware of the use of hydrogen it is unlikely that the use of hydrogen in the built environment will be imbedded in planning practices. This comes with the danger that even if the experiments are successful, a transition towards the use of hydrogen in the built environment will come to an end.

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Introduction

As a response to the urgency of climate change, 196 nations within the United Nations agreed that the rise in global temperature must be reduced to 2 degrees Celsius or preferably 1,5 degrees Celsius, in the 2015 Paris Agreement (United Nations, 2015). To meet that agreement, the Dutch government has introduced the Climate act and a Climate Agreement in 2019, stating that the government reduces the emission of greenhouse gases by 49% in 2030 and 95% in 2050 (Overheid.nl Wettenbank, 2019; Klimaatakkoord, 2019). To reach these goals, the application and usage of fossil sources of energy will be replaced with renewable sources of energy. The process of this replacement is known as the energy transition (Klimaatakkoord, 2019; Ministerie van economicsche zaken en klimaat, 2020; Kemp, 2010). In the Netherlands, this transition is likely to be very challenging in the built environment, as almost all residences are currently heated by natural gas. The envisaged energy transition in the built environment consists of disconnecting residents from the natural gas grid and heating them with sustainable sources of energy. Municipalities have to formulate a Transition vision heating before 2022, indicating the alternative sustainable heating technique that will be used in each neighbourhood (Klimaatakkoord, 2019). The national government has formulated roughly three possible alternative sustainable heating techniques for this purpose: all-electric solutions, a heat network and sustainable gasses (Expertise Centrum Warmte, 2020; Planbureau voor de leefomgeving, 2020).

In the Climate Agreement the application of hydrogen as a sustainable gas is highlighted as a key element in the energy transition (Klimaatakkoord, 2019). Hydrogen could function as an energy carrier and be a replacement for the natural gas in the energy system (Smith, Weeda & Groot, 2007). Based on the Climate Agreement and the 2020 cabinet vision on hydrogen, a National Hydrogen Program will be set up in 2021 (Klimaatakkoord, 2019; Wiebes, 2020). Currently, the program is being prepared by the Ministry of Economic Affairs and Climate, TKI new gas and the RVO, to evaluate the potential of hydrogen by experimenting with different projects in different sectors (Nationaal Waterstof Programma, n.d.; Wiebes, 2020; Gigler, Weeda, Hoogma & de Boer, 2020). The application of hydrogen in the sector of the built environment is relatively new and much is still unknow about the institutional context (Giglet et al, 2020). Because the application of hydrogen in the built environment is new, the institutional context is not adjusted to these new developments (Gigler et al, 2020). The institutional context of spatial planning is currently fundamentally changing with the upcoming new Environmental act in 2022 (Gabry, 2015; Ollongren, 2020).

The Dutch approach to addressing the energy transition relies on experimentation with the three possible alternative sustainable heating techniques. Two of the 46 Program Gas Free Neighbourhood experiments with alternative heating techniques, in Stad aan 't Haringvliet and Hoogeveen, are experiments that examine the use of hydrogen in the built environment (Programma Aardgasvrije Wijken, n.d.). However, innovative experiments often fail (van den Heiligenberg, Heimerikes, Hekkert & van Oort, 2017). Within academia the introduction of a new radical different technology in an existing socio-technical regime is examined. A new innovative technology cannot be directly implemented in practice because the incumbent socio-technical regime set barriers for deviations. Therefore, the innovation can be nurtured by doing socio-technical experiments in a protective niche, which is called strategic niche management (SNM). When the innovation is developed enough, the socio-technical regime can be changed by upscaling from the experiments. In this way experiments can contribute to a wider (sustainability) transition (Kemp, Schot & Hoogma 1998; Schot & Geels, 2008; Smith & Raven, 2012; van den Bosch, 2010; Schulz, Ophoff, Huiting, Vermaak, Scherpenissen, van der Steen & Van Twist 2020; Geels, 2019).

This thesis contributes to the understanding of how experimental hydrogen neighbourhoods are constrained. The goals of this research is to examine how experimental hydrogen neighbourhoods can be made a viable option for gas free residential developments in the Dutch energy transition. This research will examine what constraining barriers are experienced with hydrogen experimental neighbourhoods and how findings from these experiments can be upscaled and contribute to the wider energy transition. For this purpose the following central research question is formulated:

How are barriers and opportunities set by the socio-technical regime experienced with the development of experimental hydrogen neighbourhoods in Stad aan 't Haringvliet and Hoogeveen?

The main question will be answered by the following sub questions:

- What theoretical barriers are expected to hinder the development of experimental hydrogen neighbourhoods?
- Are the current experimental hydrogen neighbourhoods in Stad aan 't Haringvliet and Hoogeveen successfully addressing the barriers and opportunities that are experienced?
- How can the experienced barriers and opportunities be addressed to upscale the development of hydrogen neighbourhoods?

I will answer the first sub question in the first chapter by reviewing transition and innovations literature to derive the theoretical barriers and reviewing literature on hydrogen to identify specific hydrogen barriers. For the answering of the second and third sub question, experimental hydrogen neighbourhoods are examined as a case study within which the experiments in Stad aan 't Haringvliet and Hoogeveen are examined as units of analysis. The methodology for answering the second and third sub question is described in chapter 2. Within the case study 16 interviews are conducted and policy documents are reviewed. The third chapter presents the results from the interviews and policy documents in four key themes that determine the success of the hydrogen experiments and the progress of a potential hydrogen transition in the built environment. Finally, the sub questions and the central research question will be answered in the conclusion and implications for theory and practice will be stated in the discussion.

Societal & academic relevance

This research contributes to society by examining barriers that can constrain the experimental hydrogen neighbourhoods in Stad aan 't Haringvliet and Hoogeveen. The success of the experiments is highly important for the progress of a potential hydrogen transition in the built environment because these experiments are highly influential for policy developments (Gigler et al, 2020; Rijskoverheid, 2021). Furthermore, this research will present implications for the field of planning. Planners increasingly have to deal with planning for futures with new technologies which are not embedded in the planning system. Planning natural gas free neighbourhoods are an example of this. This research presents doing experiments as a way of dealing with planning for futures with new technologies. This research provides planners insights in how planners can deal with planning for new technologies by examining the case of experimental hydrogen neighbourhoods.

Furthermore, this research is relevant for academia because it presents how knowledge from transition and innovation studies can be used in planning by experimentation. Planning by experimentation is an approach developed by Scholl & de Kraker (2021). By examining transition and innovations literature this research contributes to understanding regime – niche transition interactions by examining constraining barriers in the interaction process. Relevant to this research are the studies of Kemp et al (1998); Schot & Geels (2008); Geels (2019) and Smith & Raven (2012) who examined how regime – niche interactions can induce a transition. Bakhuis (2020) used this perspective to examine the Dutch hydrogen transition by looking at internal niche processes. Bakhuis (2020) suggested for the large scale application of hydrogen that research is needed on external niche processes of niche - regime interactions and constraining regime barriers. This is needed because new innovative techniques often do not make it past the experimental phase (van den Heiligenberg et al, 2017). Therefore, this research will examine constraining barriers for hydrogen experiments in the Netherlands. Bai, Robert & Chen (2010); van den Heiligenberg et al (2017); Naber, Raven, Kouw & Dassen (2017) and Ceschin (2014) have indicated different regime barriers which are also potentially relevant for hydrogen experiments. Furthermore, research on experiment upscale barriers for mobility experiments in the Netherlands is done by Dijk, de Kraker & Hommels (2018). Dijk et al (2018) recommend that more research is done on barriers for upscaling from experiments. This research then contributes to this debate by examining what constraining regime barriers and opportunities are experienced with the development the experimental hydrogen neighbourhoods in Stad aan 't Haringvliet and Hoogeveen and how these barriers and opportunities can be dealt with within spatial planning to upscale from experiments.

Chapter 1: Theoretical framework

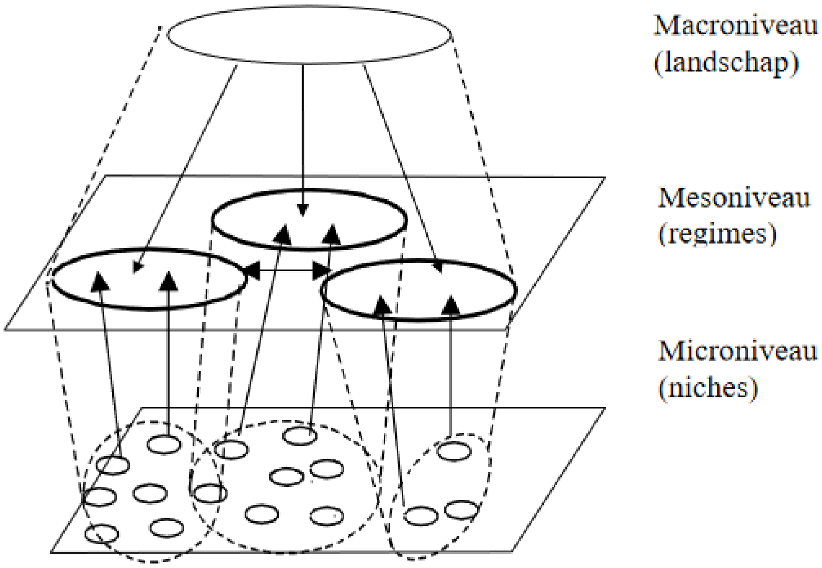
This chapter forms the academic foundation of this research. In this chapter I discuss different academic theories and debates from transition and innovation studies. These studies provide relevant insights for the planning field because planning professionals increasingly have to deal with planning for a future with technologies that are not yet developed. Transition and innovations studies provide insights on how to govern those technologies in a preferable way. Emerging techniques and transitions generate institutional uncertainty and incumbent planning practices are not able to fully address the complexity of planning problems (Reimer, 2013; Scholl & de Kraker, 2021). Based on transition and innovation studies planning by experimentation provides insights to understand these problems and to find solutions. Planning by experimentation can be defined as "*an approach that uses experimentation to innovate and improve urban planning instruments, approaches and outcomes*" (Scholl & de Kraker, 2021, p. 156). In spatial planning, strategic spatial planning focusses on changing embedded institutional practices by doing experiments (Reimer, 2013). The transition towards natural gas free neighborhoods is highly complex and a planning by experiment approach is needed. Therefore, in this research a transitions and innovation studies perspective to the hydrogen transition and the role of experiments is used.

1.1 The hydrogen transition as a socio-technical transition

The field of socio-technical transitions theory provides useful insights to think about the development of a hydrogen transition in the energy system of the Netherlands. Energy systems can be categorised as socio-technical systems because they link technology with consumers, policies and the market, in which they are crucial for the function of society (Kern & Smith, 2008; Geels, 2019;2004). In the transition studies field, the socio-technical transitions are conceptualised as follows; they focus on long term non-linear processes of socio-technical change; they focus on the mutual influence of technology and society; are interested in how novelty can be developed; and they cause a structural transformation (Kemp, 2010; Rotmans, Kemp, van Asselt, Geels, Verbong, Molendijk, 2000; van den Bosch, 2010).

The multi-level perspective (MLP), introduced by Geels & Kemp (2000) forms the foundation for socio-technical transitions theory and innovations studies (Kemp, 2010; Kern & Smith, 2008; Raven, Schot & Berkhout, 2012). The multi-level perspective is a theory to understand transitions in systems and consists of three levels (Geels, 2004), see figure 1.1. Ehe macro-level consists of the landscape. The landscape is characterizing the societal system which is beyond the control and influence of the niche and regime (Van den Bosch, 2010; Schot & Geels, 2008; Geels, 2019). The meso-level is regime level (Van den Bosch, 2010; Schot & Geels, 2008; Geels, 2019). For the purposes of this thesis the socio-technical regime of the energy system will be examined. Kemp et al (1998, p. 182) define a technological regime as follows: "*The whole complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructure that make up the totality of a technology*". A socio-technical regime is than an extension of the technical regime were also societal actors such as: users, scientists interest groups and policy makers, are considered important for the development of a new technique (Schot & Geels, 2008). Regime is used as a term to indicate both legal rules and dominate practices that function as rules (Kemp et al, 1998). According to Van den Bosch (2010, p. 41) the regime can be defined as: "*the dominant structure, culture and practises with the incumbent power and vested interests in a societal system*". A regime sets and maintains a lock-in and path-dependency of a socio-technical system (Smith & Raven, 2012; Geels, 2004). There is a techno-economic lock-in due to investments in e.g. infrastructure, there is a social and cognitive lock-in due to routines and dominant mind sets and there is an institutional and political lock-in due to regulations and legislation and the policy formation process (Geels, 2019). Hence, socio-technical regimes create constraining selection criteria for technical innovations that are outside the regime (Smith & Raven, 2012; Geels, 2004). Finally, the micro-level is the level on which innovative techniques are developed by experimenting in niches. Niches are protected spaces which are shielded from the influences of the regime (Schot & Geels, 2008; van den Bosch, 2010; Geels, 2019). Within niches a different path, than the path of the regime can be explored (Geels, 2004).

Figure 1.1 The multi-level perspective



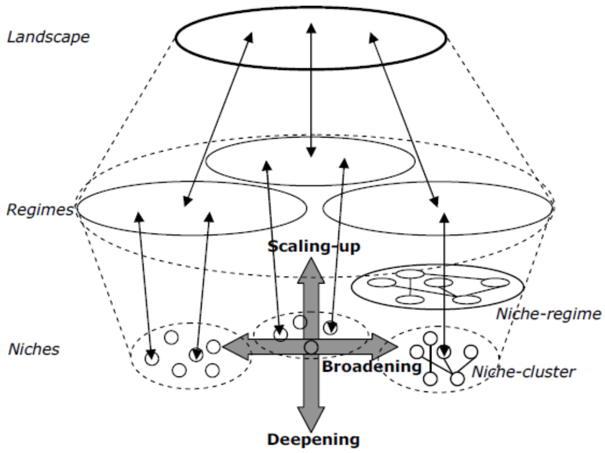
Source: Geels & Kemp, 2000

1.2 Experiments with innovative techniques

Experiments are now being conducted which use hydrogen in the built environment for heating buildings as a new innovative technique (Programma Aardgasvrije Wijken, n.d.). Experiments are a key instrument within socio-technical transitions (van den Bosch, 2010). Experiments are relevant because they allow for radical innovations to emerge and experiments create opportunities for learning (Van den Bosch, 2010; Sengers, Wieczorek & Raven, 2019; Schot & Geels, 2008). For the purpose of this thesis, an experiment can be defined as a: *"inclusive, practice-based and challenged-led initiative, which is designed to promote system innovation through social leaning under conditions of uncertainty and ambiguity"* (Sengers et al, 2019, p. 161). Sengers et al (2019) based their definition on reviewing the role of experiments in sustianble transitions within various fields of research on experiments. Therefore, this definition is suitable for the purposes of this thesis.

Experiments can contribute to a socio-technical transition by three mechanisms, this is illustrated in figure 1.2. First, through deepening, experiments in niches provide context specific knowledge on new structures, cultures and practices that are radically different than the structures, cultures, and practices within the current socio technical regime. Secondly, different niches can eventually cluster, create new networks and develop a niche-regime though broadening. Third, scaling-up refers to embedding an experiment in the regime. By scaling up experiments in niches can slowly change the structures, cultures and practices that make up the regime and thereby change the regime regulations, perspectives and institutions (Van den Bosch, 2010). In the process of scaling up, experiments can demonstrate and address regime barriers for transitions, destabilise the regime by showing its flaws and change the regime by sustaining a different approach. Scaling up innovation experiments refers to changing the regime so that the scale on which the new innovative technique can be applied is increased (Schulz et al, 2020). By scaling up the social and institutional context is changed in a way that the new technique, actors and institutions are increasingly aligned (Dijk et al, 2018). The increased scale can be broadly interpreted. It can refer to multiple experiments, conducting experiments on a larger geographical scale or including more disciplines (Schulz et al, 2020).

Figure 1.2: The contribution of experiment to a wider transition



Source: van den Bosch, 2010

1.3 Regime – niche interactions & transitions

Socio-technical transitions, such as the hydrogen transition, can be understand and managed though protecting experiments with innovative technologies in niches, such as the residential hydrogen experiments, which can eventually change the incumbent socio-technical regime. A regime change is considered a transition (Van den Bosch, 2010). This theory is called Strategic Niche Management (SNM) and is introduced by Kemp et al (1998). Kemp et al (1998) define SNM as follows:

"*Strategic niche management is the creation, development and controlled phase-out of protected space for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology and (2) enhancing the further development and the rate application of the new technology*".

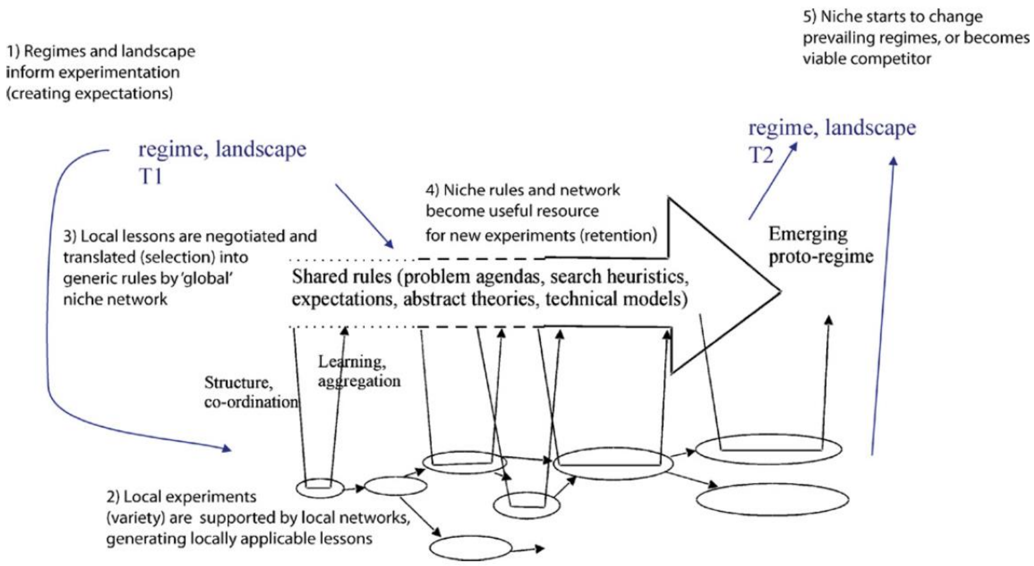
The protected space is called a niche (Kemp et al, 1998; Smith & Raven, 2012). A niche can be defined as: *"societal sub-systems that deviate from the regime and provide a context for experimenting with new, sustainable practices and related culture and structure*" (van den Bosch, 2010, p. 41). In a niche a new technology can be developed be means of experimenting without being affected by the regime. Within the niche institutional connections and adaptations can be made and learning processes can be advanced. Within a niche there are thee internal niche processes: (1) promising expectations of the technology addressing social problems need to be stimulated, because at the start of the development of the technology its future use is often not clear. (2) Learning processes on how to overcome regime barriers need to be an aim of the niche. (3) An inclusive niche actor network needs to be formulated. Though collaboration the actors must formulate a future vision and policy measures (Kemp et al, 1998).

The protection of a niche is crucial for the survival of innovations because innovations would not be able to uphold themselves when they would be exposed to the constraining selection criteria of the regime. This protection is everything that protects the innovation from the regime, from a space to experiment to institutional and regulatory arrangements (Smith & Raven, 2012). Smith & Raven

(2012) identify two types of protection: active and passive protection. Passive protection consists of everything that already existed before the innovation was introduced but can be used to protect the innovation. An example is the natural advantage an innovation can have in some geographic locations. Active protection is everything that is deliberatively and strategically created to protect the innovation, for example strategically created regulations that create advantages for using the innovation (Smith & Raven, 2012).

When focussing on external niche processes an experiment with an innovative technique in a niche can bring about a regime transition though the interaction of the different MLP levels. See figure 1.3 for the graphical presentation of how the multi-level niche – regime interactions can induce a transition. Geels (2019) identified four phases in how niche – regime interactions can induce a transition. In the first phase experiments are conducted and there is a lot of uncertainty for the innovation because techniques used in the incumbent regime are less expensive due to economies of scale, there are no markets yet for the innovation and the innovation is not yet familiar in society which can result in diminished social acceptance (Geels, 2019). In this phase the innovation needs to be shielded from the regime. Shielding entails that new innovative techniques are not assessed on regime selection criteria right away. Such a selection would limit the number of new techniques that get the chance to become viable (Smith & Raven, 2012). In the second phase the innovation becomes established in the niche which provides the innovation more security of resources (Geels, 2019). In this phase the innovation is nurtured in the niche. Nurturing means that the innovative technique is constantly being developed (Smith & Raven, 2012). In the third phase the innovation is scaled up in the regime markets (Geels, 2019). In this phase the innovation can be empowered in a way that it fits within the criteria of the regime and the innovation can benefit from elements the regime has to offer such as economies of scale, other supporting technologies and support from actors in a position of power, a strategy Smith & Raven (2012) call fit and conform. With this strategy the selection environments of the regime are unchanged. On the other hand, innovations can challenge and destabilise the regime, a process in which they change the selection environments of the regime so that they fit the innovation (Geels, 2019; Smith & Raven, 2012). This strategy is called stretch and transform (Smith & Raven, 2012). Innovations challenge the regime in different dimensions. In the economic dimension the innovation competes with competing regime technologies which are already embedded in institutions and markets. In the business dimension the innovation challenges other companies. In the political dimension the innovation challenges existing power structures. Finally in the cultural dimension the innovation challenges dominant views. Not all innovations have momentum and are successful in challenging the regime. Also, regime actors can challenge the innovation. Therefore, not all innovations make it past this phase. If the innovation makes it to the fourth phase, the innovation becomes institutionalized in regulations, consumer practices, markets and perspectives. In this phase the old socio-technical regime is replaced with a new one (Geels, 2019).

Figure 1.3 Regime – niche interactions and their relation to transitions



Source: Smith & Raven, 2012

In practice SNM is the process in which governments set up experiments with innovative technologies (Kemp et al, 1998). Kemp et al (1998) present five stages in the SNM process. First, the choice of technology must: not yet be embedded in the regime, address a social problem, have opportunities in overcoming barriers, have the prospect of being economically viable, be compatible with user needs, be feasible to organize and must have greater potential advantages than there are disadvantages. Secondly, a type of experiment must be selected in which the advantages of the technique are overshadowing the disadvantages. Third, the experiment needs to be set-up in which protecting the technique and adjusting the technique to the existing regime, needs to be balanced. Niche policies should address regime barriers by setting long-term goals, the creation of a network, the coordination of strategies and the use of financial support. Fourth, the experiment should be up scaled by governments implementing the technique in their policy. Finally, the niche protection can be lifted (Kemp et al, 1998).

1.4 Theorised barriers constraining experimentation

In this section I discuss the theorised barriers for experiments with innovative techniques that are set by the regime.

1.4.1 Regime barriers

A change in the regime can be indicated by the way regime opportunities and barriers are dealt with. For the experiment functions in a transition, as defined by van den Bosch (2010), this refers to deepening as the utilization of the regime possibilities and barriers in the context of the experiment. For broadening this refers to if the experiment deals with regime possibilities and barriers by collaborating with other experiments. Finally for scaling-up this refers to the extent to which the experiment is able to remove institutional regime barriers (van den Bosch, 2010). However, experiments often fail in scaling up; new innovative techniques do often not become available at a large scale (Kemp et al, 1998; van den Heiligenberg et al, 2017). There is not just one barrier but there are many different interrelated barriers set by the incumbent socio-technical regime that are hindering the large scale application of a new innovative technique (Kemp et al, 1998; Bai et al, 2010).

Four barrier dimensions can be identified in the literature. Economic/ financial barriers are the first dimension of regime barriers. In the early stage of experimenting with a new technology, the economic feasibility is uncertain. This uncertainty makes investors reluctant to invest, which leads to a shortage of financial resources for the experiment to take place, to develop or to be scaled up (Bai et al, 2010; van den Heiligenberg et al, 2017; Ceschin, 2014; Kemp et al, 1998). Secondly, regime regulations and institutions set barriers. Unsuitable regime regulations, the absence of new regulations, conflicting regulations and the lack of a governmental future vision form a barrier for experiments to take place, to develop or to be scaled up (Naber et al, 2017; Bai et al, 2010; van den Heiligenberg et al, 2017; Ceschin, 2014; Kemp et al, 1998). Political barriers form the third regime barrier. Political barriers are caused by scepticism towards new technologies, the reluctantly of governments to change due to vested interest of political actors and the process of political change takes time (Bai et al, 2010; van den Heiligenberg et al, 2017; Kemp et al, 1998). Finally, there are technique and infrastructure barriers caused by a disconnection with existing techniques and infrastructure or the new technique is of insufficient quality (van den Heiligenberg et al, 2017; Kemp et al, 1998).

1.4.2 Upscale barriers

Additionally, Dijk et al (2018) identified three regime barriers for scaling up from experiments. The first barrier for upscaling from experiments is the way that is thought about experts. Because of the nature of 'innovation' in innovative experiments, experiments are mostly dominated by technical experts, hindering even ambitious forms of participation. This technical expert driven approach leads to specialization which narrows the scope of the experiment and constrains the upscaling possibilities. This constrain can be addressed by introducing collaboration with other disciplines, the inclusion of more stakeholders from other disciplines and future users and conducting more successful experiments.

A second barrier for upscaling from experiments is the limited representativeness of the design, conditions, rules and actors of an experiment. When an experiment has limited representatives, upscaling from this experiment would not be useful since it would not apply for other cases (Dijk et al, 2018). Limiting the inclusion of actors comes with another disadvantage of reproducing existing power structures within the experiment (Dijk et al, 2018; Schulz et al, 2020). By including more diverse actors and future users and making the scope of the experiment more holistic this constrain could be dealt with (Dijk et al, 2018).

Third, because only limited actors are involved there is a lack of consensus among the excluded actors on the merits of the innovation experiment. This barrier can be addressed by including participation in the development process of the future vision at the beginning of the experiment. Furthermore, framing the experiment in a way that everyone is included could help addressing this barrier (Dijk et al, 2018).

1.5 The specific opportunities and barriers for using hydrogen in the Netherlands

In this section I discuss the specific opportunities and the potential regime barriers that can constrain the experiments with hydrogen in the built environment based on hydrogen studies.

1.5.1 The potential of using hydrogen in the Dutch energy transition

Hydrogen is manufactured and is not a primary source of energy that exists in nature, it must be generated with another energy source (Balat, 2008; Najjar, 2013). In the energy transition, hydrogen has the most potential when it is generated from renewable sources of energy, instead of being generated from fossil fuels. When hydrogen is created from renewable energy sources, hydrogen is referred to as 'green hydrogen' (Dincer, 2012). Although hydrogen is not a primary energy source, hydrogen is important for the energy transition because it can function as a clean secondary source of energy by carrying energy (Balat, 2008; Najjar, 2013). Through hydrogen energy can be transported. At the destination hydrogen can be burned and heat can be delivered (Najjer, 2013). Compared to other fossil energy sources and energy carriers: hydrogen has the highest energy carrying ability which makes the use of hydrogen more efficient than the use of natural gas and hydrogen is a clean secondary energy source because with the combustion of hydrogen the only emissions are water and a low amount of nitrogen oxides (Balat, 2008; Najjer, 2013; KIWA & Netbeheer Nederland, 2018). Using hydrogen as an energy carrier has also advantages over using energy directly from renewable energy sources because hydrogen can be captured and stored. Storing and capturing energy is till now a deficiency of renewable energy sources like wind and solar energy. When clean energy can be stored fluctuations can be dealt with in a more efficient way (Balat, 2008; Detz, Lenzmann, Sijm & Weeda, 2019). In terms of safety, when the use of hydrogen is compared to natural gas, the use of hydrogen has the advantages of a higher evaporation rate, which decreases the risk of a fire or explosion and the use of hydrogen cannot lead to carbon monoxide poisoning (Najjar, 2013; Sherif, Barbir & Vezirogula, 2005; KIWA & Netbeheer Nederland, 2018).

The Netherlands has three potentially advantageous conditions for a transition towards a (partly) hydrogen based energy system. First, the Netherlands has a large, well-developed natural gas network (Smith et al, 2007). This is conductive for a transition towards an energy system on hydrogen (Haeseldonckx & D'haseleer, 2007). According to KIWA & Netbeheer Nederland (2018) the Dutch natural gas network is well usable for the distribution of 100% hydrogen. Secondly, the Netherlands being a coastal country, has the potential to generate hydrogen from offshore wind energy from wind farms in the North Sea (Jepma & van Schot, 2017). Third, in Europe and in the Netherlands much research is done on the applicability of hydrogen as an energy carrier in the energy system (Mans, Alkemade, van der Valk & Hekkert, 2008; Bakhuis, 2020). The Netherlands has a front-runner position in the hydrogen industry due to early experimentation which led to knowledge and network creation (Bakhuis, 2020).

Hydrogen can be used in the built environment when other sustianble alternatives such as electric heat pumps and heat networks are not an option. Electric heat pump and heat networks are for example not suitable for old characteristic buildings or for buildings situated in an remote areas (Detz et al, 2019).

1.5.2 Specific barriers for using hydrogen in the Dutch energy transition

There are also some specific barriers identified for the use of hydrogen in the Dutch energy transition (in the built environment).

Technique & costs

The availability of green hydrogen (in the built environment) is dependent on the costs of hydrogen compared to other sustainable energy alternatives, the costs and availability of sustainable energy from which green hydrogen can be produced and the available technology to produce hydrogen (Detz et al, 2019). Despite the potential of green hydrogen, hydrogen was in 2012 still mainly produced from fossil fuels (Dincer, 2012). The production costs of hydrogen from fossil fuels is lower than the production costs of hydrogen from renewable energy sources (Smith et al, 2007; Dincer, 2012). Hydrogen produced from fossil fuels is referred to as 'grey hydrogen' (Jepma & van Schot, 2017; Detz et al, 2019). When hydrogen can be more cost efficiently produced from renewable energy sources it becomes more attractive (Smith et al, 2007; Detz et al, 2019). Furthermore, the natural gas grid seems adequate for using hydrogen. However, alternations on the gas grid could bring extra costs (Detz et al, 2019). Additionally, end use appliances are mostly not suitable for hydrogen. Burning hydrogen in existing boilers can lead to flame strike. Also cooking on hydrogen comes with the disadvantage of an invisible flame. The replacement of end use appliances will also bring extra costs (KIWA & Netbeheer Nederland, 2018).

Safety

The use of hydrogen has implications since it is a hazardous substance. According to KIWA & Netbeheer Nederland (2018) the use of hydrogen has safety disadvantages when compared to natural gas, which has already been used on a large scale for a long time in the built environment in the Netherlands. Because hydrogen is a different substance than natural gas, hydrogen has different physicochemical properties than natural gas and therefore different safety regulations need to be in place (KIWA & Netbeheer Nederland, 2018). The main risk of hydrogen is an explosion, due to the ignition and combustion characteristics of hydrogen (Kim & Moon, 2008; Gandia, Arzamendi, Diéguez, 2013; Najjar, 2013). Hydrogen has a lower ignition temperature and energy, wider explosion limits, a higher combustion speed and lift, a higher flame temperature and the flame is hardly visible (KIWA & Netbeheer Nederland, 2018; Najjar, 2013; Sherif et al, 2005). Because hydrogen is the smallest molecule, leakages could occur faster and more often (Sherif et al, 2005; Najjar, 2013). Furthermore, embrittlement can take place with some metals which also could result in leakages (Najjar, 2013). When hydrogen is released hydrogen has, similar to natural gas, no smell (KIWA & Netbeheer Nederland, 2018; Najjar, 2013). Hydrogen is not toxic but in case of a leak, the gas can fill a non-ventilated room and reduce oxygen in the process which can lead to suffocation (Gandia et al, 2013). Additionally, the energy density of hydrogen is lower than natural gas which will increase the gas volume in the gas grid by three times and will result in a higher flow velocity. Hence, the gas outflow with a leakage will be higher. However, because the energy density is lower, there is no higher safety risk. Higher gas velocity can also lead to noise pollution however, much is unclear about this (KIWA & Netbeheer Nederland, 2018).

It remains unclear whether the use of hydrogen is more dangerous than the use of natural gas. According to KIWA & Netbeheer Nederland (2018) because both hydrogen and natural gas are different gasses with different characteristics, it is not clear to say which gas is more safe than the other. On the one hand Gandia et al (2013) argue that the physicochemical properties of hydrogen cause a more severe risk than natural gas. However, Kim & Moon (2008, p. 5888) argue that hydrogen is "*no more dangerous than other flammable fuels such as gasoline and natural gas*".

The perception of the safety of hydrogen and acceptation of the risks by residents is important for the extent to which the large scale implementation of hydrogen will be successful (KIWA & Netbeheer Nederland, 2018; Najjar, 2013). According to KIWA & Netbeheer Nederland (2018) citizens can be informed by an information campaign and demonstration projects.

Policy & regulations

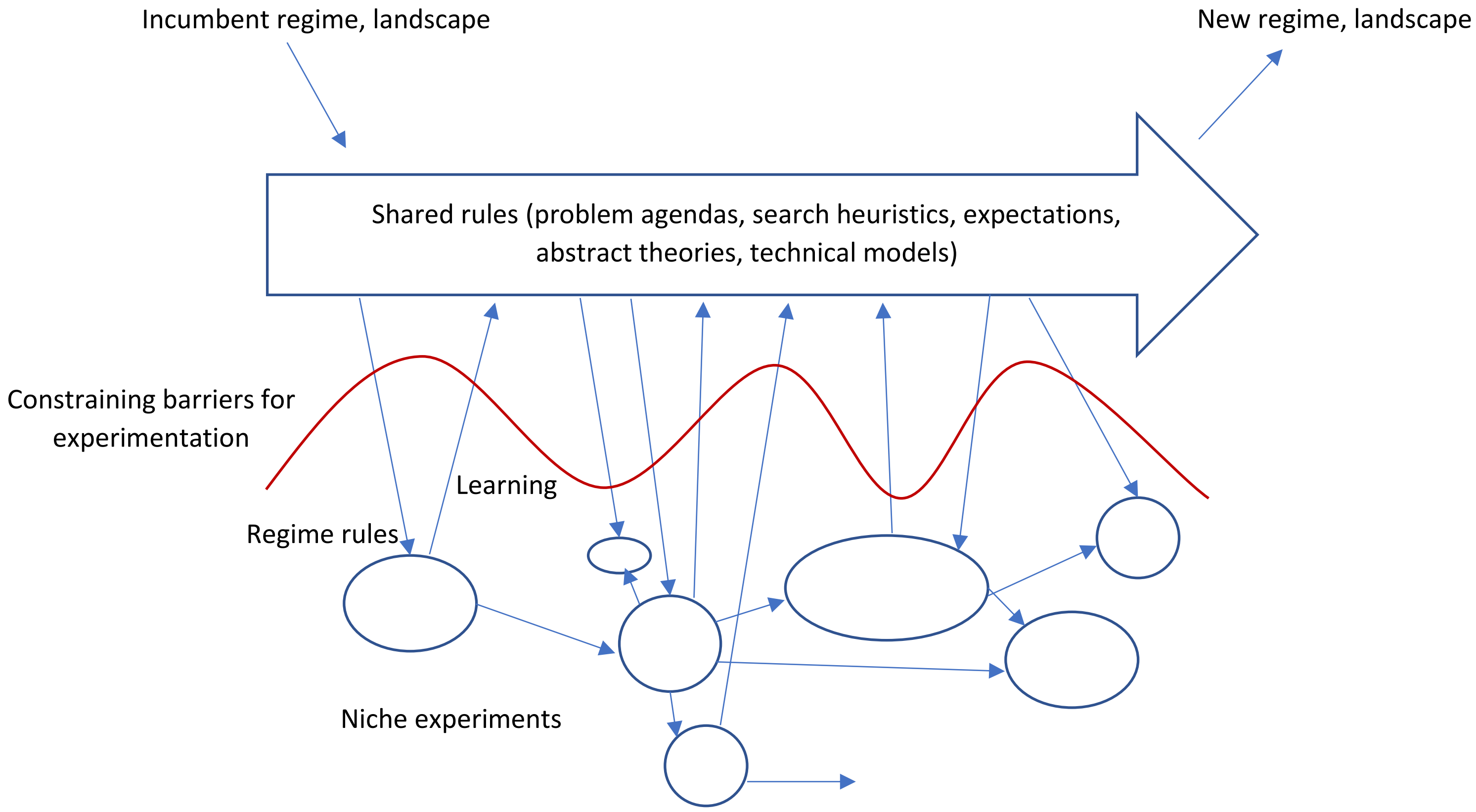
The Dutch government has positive expectations for the role hydrogen can play in the energy transition, however concrete policy and regulations are missing (Bakhuis, 2020). Industrial parties and the governments have other expectations for the use of green and blue hydrogen and there is unclarity about infrastructural responsibility and regulations, this unclarity of hydrogen expectations and regulations leads to actors being reluctant to invest (Bakhuis, 2020; Detz et al, 2019). Based on the unclarity of hydrogen expectations network formation is in an early stage. The existing networks include many relevant actors but inclusion of different sectors in a network is lacking. More experimentation is needed for more clear expectations and regulations but the unclarity of expectations and regulations leads to the reluctancy to experiment, for actors to get involved and to invest. Therefore, learning processes are still in an early stage. More experimentation is needed to advance the learning processes and to gain more knowledge. This is needed to base funding on, to enhance buyer-supplier connections and to align expectations between the government and industry. Furthermore, hydrogen experimentation so far only takes place on a small scale, however, to gain more knowledge, hydrogen experimentation on a larger scale is necessary. Time and funding are the main constraints for large scale experimentation (Bakhuis, 2020).

1.6 Conclusion theoretical framework

By examining the field of transition and innovation studies, the potential hydrogen transition in the energy system of the Netherlands can be characterised as a socio-technical transition. In the hydrogen transition, experiments are now being conducted with the use of hydrogen in the built environment to heat buildings as an innovative technique (Programma Aardgasvrije Wijken, n.d.). Experiments are a key instrument in socio-technical transition because they allow for radical innovations to emerge and create opportunities for learning (Van den Bosch, 2010; Sengers et al, 2019; Schot & Geels, 2008). Experiments can contribute to a socio-technical transition be the means of deepening, broadening and scaling-up (Van den Bosch, 2010). Experiments with radical different techniques benefit from the protection of a niche because the incumbent socio-technical regime sets constraining barriers for radical different innovations (Kemp et al, 1998; Smith & Raven, 2012; Geels, 2019). Within the niche, innovative techniques can be nurtured by the means of experimentation till they can be scaled up and replace the old regime with a new regime were there the innovative technique is imbedded in (Smith & Raven, 2012; Geels, 2019). However, niches are not always successful in changing the regime (Geels, 2019). Theorised constraining regime barriers that could be identified are: economic & financial barriers, regulatory barriers, political barriers and technical & infrastructural barriers (Naber et al, 2017; Bai et al, 2010; van den Heiligenberg et al, 2017; Ceschin, 2014; Kemp et al, 1988). Constraining barriers for scaling up are: the dominant role of experts, the limited representativeness of an experiment and limited actors involved with the experiment (Dijk et al, 2018). For hydrogen in the built environment experiments the following specific constraining regime barriers could be identified in the literature: technique & costs, safety and policy & regulations barriers (Detz et al, 2019; Dincer, 2012; Smith et al, 2007; Jepma & van Schot, 2017; KIWA & Netbeheer Nederland, 2018; Kim & Moon, 2008; Gandia et al, 2013; Najjar, 2013; Sherif et al, 2005; Bakhuis, 2020). To help planners cope with planning a future with new technologies, I will examine in this research whether constraining regime barriers for hydrogen experimental neighbourhoods are experienced in practice and how these barriers can be addressed.

Figure 1.4 presents the theoretical findings and the contribution of this research to the knowledge on barriers in regime – niche interactions. Figure 1.4 is based upon the model Smith & Raven (2012) presented. The model Smith & Raven (2012) presented focusses on how niche – regime interactions can induce a transition by using a multi-level perspective. For the purposes of this thesis I added the 'constraining barriers for experimentation' dimension.

Figure 1.4 Conceptual model



based upon Smith & Raven, 2012

Chapter 2: Methodology

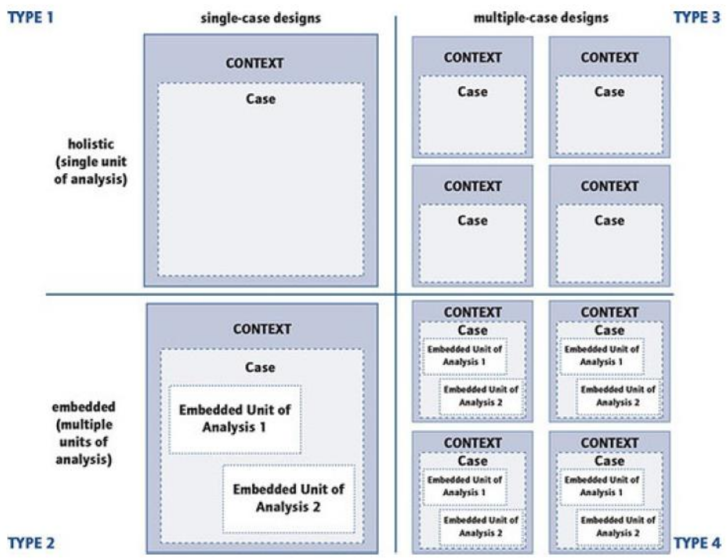
In this chapter the methodological approach of this research is described and substantiated.

2.1 General strategy

Based on Bryman (2012) the central research question that is examined in this thesis has an interpretivist epistemology and a constructivist ontology and is therefore answered by using a qualitative research strategy and methods. The research question has an interpretivist epistemology because it examined subjective meaning of how barriers and opportunities are experienced within the two experiments. Following this interpretivist epistemology comes a constructivist ontology which assumes that social meaning and phenomena are created and constantly shaped by social actors. The barriers, opportunities and the socio-technical regime are what social actors make of it and can be examined by examining experiences of social actors. The collection and analysis of the data is done by using an inductive approach whereby empirical findings created a contribution to the theoretical knowledge.

This research has a case study research design. According to Yin (2018) research questions that asks 'how' questions can be examined by using a case study. Furthermore, the use of a case study research design is well usable when the researcher cannot influence behaviours and the research examines contemporary events. When using a case study to answer a research question, an inductive approach can be used where findings can be generalized to theory but not to a certain population (Yin, 2018). Based on Yin (2018) this research will use a single case study design. This research examined experimental residential hydrogen neighbourhoods as a case in the same context of the wider transition towards a natural gas free built environment. A single case study design can be used when the case is critical, unusual, common, revelatory or longitudinal (Yin, 2018). Experimental residential hydrogen neighbourhoods are an unusual case because in the spectrum of experiments that contribute to sustainability transition, because there are only a few residential hydrogen experiments in the Netherlands (Gigler et al, 2020). This single case study design examined two units of analysis by looking at two different experimental neighbourhoods to avoid a too narrow approach, which makes this research an embedded single case study design, type 2 in figure 2.1. With such a case study approach it is important to distinct the units of analysis from the case (Yin, 2018).

Figure 2.1 types case study designs

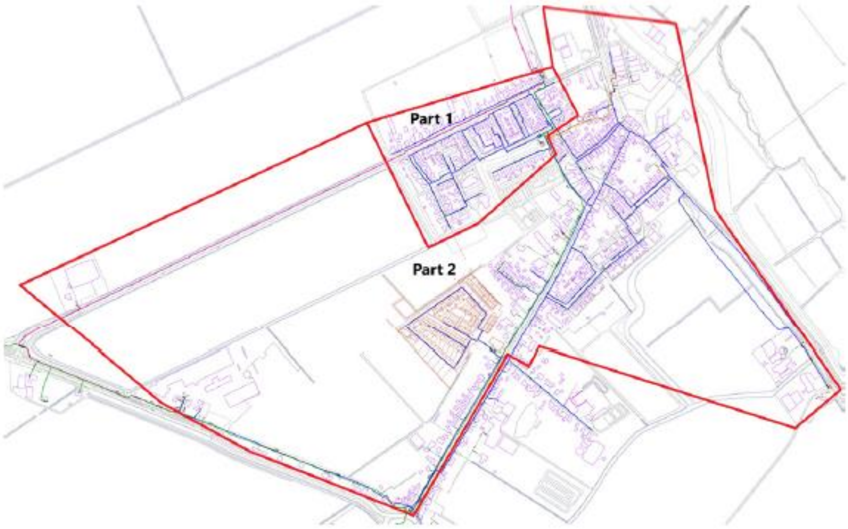


Source: cosmos corporation as cited in Yin (2018)

2.2 Research case and units of analysis

For this single case study research experimental residential hydrogen neighbourhoods were examined as a case. Because this is an embedded single case study design, multiple units of analysis were examined. The following two experiments were examined as units of analysis: City Natural Gas Free in Stad aan 't Haringvliet and Hydrogen Neighbourhood in Hoogeveen which contains the neighbourhoods of De Erflanden & Nijstad-Oost. See figure 2.2 and 2.3 for the location of the experiments and see table 2.1 for the different characteristics of the units of analysis.

Figure 2.2 City Natural Gas Free Stad aan 't Haringvliet



Source: Stedin & Kiwa, 2019

Figure 2.3 Hydrogen Neighbourhood Hoogeveen

Source: Aué, van der Meij, Hengeveld, Tempelman, Meijer, Boer, Hazenberg, Teerling, Pereboom & Elving, 2020

Table 2.1: Characteristics of the units of analysis

Neighbourhood	**Unit of analysis 1: Stad aan 't Haringvliet***	**Unit of analysis 2: Erflanden & Nijstad-Oost****
Country	The Netherlands	The Netherlands
Municipality	Goeree-Overflakkee	Hoogeveen
Province	Zuid-Holland	Drente
Aim of the experiment	Using hydrogen in the existing built environment	Using hydrogen in a new built neighbourhood (Nijstad-Oost phase 1) and in an existing built environment (Erflanden phase 2)

* source: Stedin & Kiwa, 2019

** source: Aué et al, 2020

Because the two units of analysis are experiments of similar size on local/ neighbourhood level, have the same objective of using green hydrogen in the existing built environment and operate within the same Dutch institutional context and the context of the same socio-technical regime, these two experiments are considered as multiple units of analysis within the same case and context, see figure 2.1. These two experiments are part of the Program Gas free Neighbourhoods experimental program for natural gas free developments (Programma Aardgasvrije Wijken, n.d.), are two of the four experiments that are mentioned in the *Multi-year programmatic approach for hydrogen* (Gigler et al, 2020) which is used by the government for their upcoming hydrogen strategy (Wiebes, 2020), are the two experiments that lay at the foundation of the National Hydrogen Program that is currently being developed (Nationaal waterstof programma, n.d.) and are the two experiments that concluded a Green Deal with the national government and are used by the national government for the formulation of regulations and policy (Rijksoverheid, 2021). Other residential hydrogen experiments in Ameland, Uithoorn and Rozenburg are on a smaller scale and do not have a direct link to influence national regulations and policy (Duurzaamameland, 2021; Stedin, n.d.; 2018).

2.3 Methods for data collection, processing and analysis

With a case study research, interviewing is an appropriate method for data collection (Yin, 2018). Interviews are useful for obtaining explanations for social phenomena and with interviews respondents perspectives can be interpreted (Yin, 2018). To answer the second and third sub questions, 16 in-depth semi structured interviews were conducted. Professional stakeholders involved with the two units of analysis were interviewed on their experience, regime actors were interviewed on their experience and experts were interviewed on their knowledge. Interviewing experiment stakeholders on their experiences with regime barriers is a proven method by van den Heiligenberg et al (2017); Naber et al (2017) and Ceschin (2014). See table 2.2 for the list of respondents.

With semi-structured interviews there is an in-depth focus on the subjects that are examined but there is also room for the interpretation of the interviewee (Bryman, 2012). Based on Bryman (2012), an interview guide with questions was drafted on forehand for the semi-structured interviews, see appendix 1. Based on Bowen (2009) policy documents and the theoretical framework provided input for context of the interview and for the interview questions. Due to the COVID-19 pandemic all interviews were conducted by telephone or by using MS Teams. Doing interviews online saved travel time, which made it possible to conduct more interviews. However, there are also disadvantages of doing interviews online such as the absence of nonverbal communication and faltering connection, which is also indicated by Bryman (2012). During the time of data collection I have visited the potential site of the Hoogeveen experiment.

The interviews were recorded with permission of the interviewee and were transcribed. Transcribing interviews overcomes the limits of just using memory, makes it possible to further examine what has been said and limits biases (Bryman, 2012). Based on the transcriptions summaries based on codes conducted from the theoretical framework were drafted and sent back to the respondents for a check of the content and interpretation, see Appendix 2 for the codes used in the summaries. Coding the data makes the analysis more efficient, more transparent and gives new opportunities such as counting frequencies. There are also a few risks with coding data, for example the data becomes quantified, fragmented and decontextualised (Bryman, 2012). Based on the interview transcripts and the checked coded interview summaries the data was analysed and four key themes were found on which the result chapter is based. The themes were all striking and interesting topics during the interviews. For the analysis of the four themes there was a constant check with the original transcripts. The information from the interviews in the result chapter was supplemented with information from policy documents. To guarantee the quality of qualitative research it is recommended to have multiple sources of evidence. Convergences between the evidence from both sources improves the quality of the research, reduce biases and verifies statements (Bowen, 2009; Yin, 2018). Finally, connections were made between the results and the theory introduced in the theoretical framework and the results chapter was sent back to the respondents to verify the way the respondents were referred to and to check the content of the results chapter. In appendix 3 the quotes used in the results chapter are stated in their original version.

To trace back were the information in the results chapter comes from, but to also protect the anonymity of the respondents, respondent specific codes are introduced table 2.2. The codes are based on the number of the respondent and if they are a expert/ niche actor/ regime actors or intermediary actor. An expert is in this case someone who is not involved in the experiments and has a lot of expert knowledge. A niche actor is someone who is involved in the experiment. A regime actor is someone who is not involved in the experiment and is a part of the energy regime. Finally, an intermediate actor is someone who is involved in the experiment but who is also part of the energy regime.

2.4 Quality of the research

To guarantee the quality of the research, construct validity, internal validity, external validity and reliability should be optimized. This was done based on the criteria Yin (2018) set up. First, to improve construct validity this research will use multiple sources of evidence, namely interviews and a policy documents. Furthermore, the interview summaries and the results chapter were sent back to the respondents for a quality and interpretation check. Secondly, explanatory building and logic models are used to improve internal validity, by describing the case and complex processes within the case in the first section of the results chapter. Third, to guarantee external validity in this single case study, this research is based on a theoretical framework. Finally, reliability is guaranteed by describing all methods used in depth and providing all materials and evidence with this research so that the chain of evidence can be followed by others.

Table 2.2 Respondents

	Expert/ Niche actor/ Regime actor/ intermediary actor	Hoogeveen/ Stad aan 't Haringvliet	Code	Function	Date of the interview
1	Expert (Ex)	-	EX1	Researcher	12-04
2	Intermediary Actor (IA)	Stad aan 't Haringvliet (S)	IAS2	Supplier	12-04
3	Regime Actor (RA)	-	RA3	Government	12-04
4	Niche Actor (NA)	Stad aan 't Haringvliet (S)	NAS4	Advisory consultancy	15-04
5	Intermediary Actor (IA)	Stad aan 't Haringvliet (S)	IAS5	Supplier	16-04
6	Regime Actor (RA)	-	RA6	Government	19-04
7	Expert (Ex)	Anonymous	EX7	Anonymous	Anonymous
8	Intermediary Actor (IA)	Hoogeveen (H)	IAH8	Safety advisor	20-04
9	Niche Actor (NA)	Hoogeveen (H)	NAH9	Advisory consultancy	21-04
10	Intermediary Actor (IA)	Hoogeveen	IAH10	Supplier	21-04
11	Niche Actor (NA)	Hoogeveen (H)	NAH11	Advisory consultancy	21-04
12	Niche Actor (NA)	Stad aan 't Haringvliet (S)	NAS12	Supplier	22-04
13	Intermediary Actor (IA)	Stad aan 't Haringvliet (S)	IAS13	Government	28-04
14	Regime Actor (RA)	-	RA14	Government	29-04
15	Niche Actor (NA)	Stad aan 't Haringvliet (S)	NAS15	Manager	10-05
16	Niche Actor (NA)	Hoogeveen (H)	NAH16	Government	17-05

Chapter 3: Results

This chapter presents the results of the conducted interviews combined with the knowledge gained from policy documents. In this chapter I present four key themes which can constrain the extent to which the residential hydrogen experiments will be successful, provide opportunities and determine how a potential transition towards hydrogen in the built environment will progress.

3.1 The context, the status and the comprehensiveness of hydrogen experimentation in the built environment in the Netherlands

The two hydrogen experiments in Stad aan ‘t Haringvliet and Hoogeveen are influenced by developments surrounding them and the experiments are expected to also change their surroundings. This thesis shows that the two hydrogen experiments in Stad aan ‘t Haringvliet and Hoogeveen have the same objectives but differ in underlying rational for experimentation and selecting hydrogen as alternative for natural gas and comprehensiveness. This might influence the extent to which the experiments are successful.

3.1.1 Hydrogen experiments in the built environment

Multiple formal agreements have reached that hydrogen is currently being considered as a sustainable alternative for the use of natural gas in the built environment in the Netherlands in the context of the Dutch energy transition from which the Climate Agreement forms the basis (Klimaatakkoord, 2019; Programma Aardgasvrije Wijken, n.d.; Wiebes, 2020; Nationaal Waterstof Programma, n.d.; Expertise Centrum Warmte, n.d.). These policies, also stated in table 3.1, amount to a considerable attempt by the Dutch government to create a niche for hydrogen.

Table 3.1 Relevant governmental documents and policies

Document/ policy	Date of publication/ foundation	Source
Climate Argeement	2019	Klimaatakkoord, 2019
Program Natural Gas Free Neighbourhoods	Founded: 2018	Programma Aardgasvrije wijken, n.d.
Expertise Centre Heating	Founded: 2019	Expertise Centrum Warmte, n.d.
Cabinet vision on hydrogen	2020	Wiebes, 2020
National Hydrogen Program	Founded: 2021	Nationaal Waterstof Programma, n.d.

The Climate Agreement and the 2020 cabinet vision on hydrogen announced a National Hydrogen Program (Klimaatakkoord, 2019; Wiebes, 2020). Currently the National Hydrogen Program is being developed to support hydrogen innovations in different sectors from which the built environment is one (RA14; Wiebes, 2020; Nationaal Waterstof Programma, n.d.). For a long time, the focus for the application of hydrogen has been on the industry and mobility sectors. Therefore, there is already more knowledge and information about these sectors. The industry and mobility sectors are still dominant, but since the summer of 2020, the use of hydrogen in the built environment is being looked at in a different way. First the focus of using hydrogen in the built environment was on researching and creating preconditions. Now it is seen as a realistic option. Due to the recent interest in the built environment for the use of hydrogen, less is known about it. With the recent development of a built environment section in the National Hydrogen Program the national government is lagging behind in the interest that there has been in the recent years (RA14).

Hydrogen, can be a suitable alternative for natural gas in the built environment when other natural gas alternatives are not an option or relatively more expensive (IAS2; IAS5; IAH8; NAH9; NAS15; NAH16; Klimaatakkoord, 2019; Giglet et al, 2020; Nationaal Waterstof Programma, n.d.). All-electric solutions and heating networks are not an option or relatively more expensive when buildings are not possible to be well insulated because they are old or have a monumental status. All-electric solutions and heating networks are therefore the best option for relatively new buildings and new built buildings. Hydrogen could then be an option for older buildings. Furthermore, heating networks are not an option when there is no heating source nearby and the buildings are widely distributed. Heating networks are therefore a better option in urban areas and hydrogen could be a possible solution for more rural areas (IAS2; IAS5; IAH8; NAH9; NAS15; NAH16).

In the Climate Agreement it is announced that experimentation with hydrogen in the built environment will be conducted in order to examine the applicability (Klimaatakkoord, 2019). The expectation from the government and network operators is that the large scale application of hydrogen will not be an option before 2030. For the large scale application of hydrogen in the built environment to become an option after 2030 it is necessary to gain more knowledge and experience by doing experiments (IAS2; IAS5; RA14; NAH9; IAH8; IAH10; NAH16; RA6; Klimaatakkoord, 2019; Wiebes, 2020; Nationaal Waterstof Programma, n.d.). Experiments have been conducted in, among other places, Ameland, Rozenburg, Uithoorn and on the Green Village in Delft. In Ameland in 2007, hydrogen was blended into natural gas in the natural gas network. In 2018, the use of 100% hydrogen boilers in an apartment complex in Rozenburg started. In the autumn of 2020, homes for demolition in Uithoorn were successfully converted from the use of natural gas to the use of hydrogen (IAS2; IAS5). Finally, the Green Village is a field lab for sustainable innovations in the built environment. A hydrogen street is part of this Green Village. Here it is examined whether the natural gas network can be used for the application of hydrogen, how gas stations and gas meters function and which safety requirements are necessary (The Green Village, n.d.).

In the 2020 cabinets vision on hydrogen, the National Hydrogen Program and the Program Gas Free Neighbourhoods, the ongoing hydrogen experiments in Stad aan ‘t Haringvliet and Hoogeveen are mentioned as the relevant experiments that will generated more knowledge and experience for policy and for the use of hydrogen in the built environment (Wiebes, 2020; Nationaal Waterstof Programma, n.d.; Programma Aardgasvrije Wijken, n.d.). These experiments are different from earlier experiments because residents are involved, there is no alternative for if the hydrogen supply fails and these experiments involve a larger scale (IAS2). The aim of both the experiments is to use hydrogen in the existing natural gas network in existing residential neighbourhoods. Both experiments are in a research and preparing phase and hydrogen is not yet applied in the network and buildings. It is expected that hydrogen is applied in the neighbourhoods in 2025 if all conditions are met. The Stad aan ‘t Haringvliet and Hoogeveen experiments strive to be representative so that the use of hydrogen in the built environment could (partially) be upscaled to other places (IAS2; NAS4; IAS5; RA6; NAH9; IAH10; IAS13; RA14; NAH16). However, this thesis shows that the underlying rational for experimentation and selecting hydrogen and comprehensiveness of the experiments differs because the experiments are initiated from different angels, other natural gas alternatives are disregarded based on different argumentations and the experiments use different types of buildings. Table 3.1 shows the characteristics of the two experiments.

Table 3.2: Characteristics of the experiments

	Stad aan ’t Haringvliet	**Hoogeveen**
Province	Zuid-Holland	Drente
Municipality	Goeree-Overflakkee	Hoogeveen
Initiative	Residents ***	Municipality ***
New construction or existing buildings	Existing buildings*	Phase 1: Nijstad-Oost: new construction** Phase 2: Erflanden: existing buildings **
Construction year buildings	Between: 1534-2020**** Average: 1952****	Phase 1: Nijstad-Oost: 2021** Phase 2: Erflanden: Between: 1990-2020*****
Connections to a New hydrogen grid	none	Nijstad-Oost: 100**
Connections to the natural gas network	522*	Errflanden: 427**
Green or grey hydrogen?	Green hydrogen*	Green hydrogen**
Part of the following programs:	Program Natural Gas Free Neighbourhoods *** H2GO*** The Green Deal***	Program Natural Gas Free Neighbourhoods *** Hydro Greenn*** The Green Deal***
Rationale for selecting hydrogen	All-electric solutions not an option because many buildings are not possible to be well insulated*&*** Heating network not an option because there is not heating source nearby*&***	All-electric solutions and heating network will be more expensive due to larger insulation and infrastructural investment costs **&***

*source: Stedin & Kiwa, 2019
**source: Aué et al, 2020
***Source: IAS2; RA3; NAS4; IAS5; RA6; NAH9; IAH10; IAS13; RA14; NAS15; NAH16
****Source: Kadastralekaart, 2021
***** Source: Allecijfers, 2021a

3.1.2 Stad aan ’t Haringvliet: City Natural Gas Free

A group of residents interested in natural gas alternatives in the context of the energy transition initiated the experiment in Stad aan ‘t Haringvliet (IAS2; IAS5; NAS15). They were considering different alternatives and based on different analyses hydrogen was viewed as the best solution, as is illustrated by quote 1:

“It is a bottom-up initiative, the residents at one point said in 2017 we want to see what is possible in the field of the energy transition. (…) We Started doing analyses and if you then look (…) at the village of Stad aan 't haringvliet, where there are no high-rise buildings, where there is no residual heat in the area, where it becomes very difficult to bring to a low temperature heating system, where there are all detached individual homes that are still poorly to very poorly insulated, yes, then a sustainable gas is perhaps the only solution from a social point of view, yes, hydrogen was then also mentioned at a given moment and the residents are currently being included in the process, a full-fledged project partner also together with a lot of other parties. So it ultimately comes from the residents and it has been running for years.” (IAS2)

Stad aan ‘t Haringvliet has many old and monumental buildings, on average the buildings are constructed in 1952 (Kadastralekaart, 2021; Rijksmonumenten, 2021). Most building are built between 1950 and 1970. There are also some new built houses constructed in the period 2010-2020 (Allecijfers, 2021b). Old monumental buildings are unsuitable to be well insulated. This makes most buildings in Stad aan ‘t Haringvliet unsuitable for all-electric solutions (IAS2; IAS5; IAS14). Furthermore, Stad aan ‘t Haringvliet has no heating source nearby which makes Stad aan ‘t Haringvliet unsuitable for a heating network (Stedin & KIWA, 2019; IAS2; IAS5). Additionally, on the island of Goeree-Overflakkee there is a surplus of renewable energy which can be used to generate hydrogen (RA6). This all led to the rational for selecting hydrogen as alternative for natural gas.

The experiment is being carried out by nine project partners and 15 involved residents. The residents compose a sounding board group. A project manager has been hired who works for the common good. In formal decision-making, the residents have a decisive say, but this is done more broadly than with only the 15 involved residents. For this the village is approached (NAS15).

The Stad aan ‘t Haringvliet experiment is part of the H22GO program. The H2GO is set up by the province of South Holland and the municipality of Goerree-Overflakkee, more than 30 parties are involved and it consists of eight hydrogen projects at Goeree-Overflakkee. Various stakeholders are connected to the program so that they can exchange knowledge amongst each other. For example, they can make use of the knowledge of TU Delft and TNO, and can make use of the different (network) capacities, for example of the province and its lobbying possibilities towards Europe. The H2GO program plays a facilitating role for City Natural Gas Free and the municipality has the directing role that is required for the subsidy received from the Program Natural Gas Free Neighbourhoods (NAH4; IAS13).

3.1.3 Hoogeveen: Hydrogen Neighbourhood Hoogeveen

The experiment in Hoogeveen consist of two phases. In the first phase hydrogen is used in the new built neighbourhood Nijstad-Oost for which a new off grid gas network is going to be used. The municipality of Hoogeveen had the intention to realize the new neighbourhood Nijstad-Oost. The idea was to give the neighbourhood a sustainable character. The municipality then held an energy workshop with various stakeholders, including: the province, the waterboard and the network operator. Through the province the municipality came in contact with the Hydro Green platform (NAH16). This is a hydrogen innovation platform in the North of the Netherlands with 22 partners among which are: knowledge institutions, governments and private companies and they were looking for pilot projects (Aué et al, 2020; NAH16). The municipality then suggested turning Nijstad-Oost into a pilot project (NAH16). The Hydro Greenn consortium has delivered the report *Hydrogen neighborhood: plan for hydrogen in Hoogeveen* (Aué et al, 2020) after which the consortium ended (NAH8; IAH10; NAH16). After the completion of the Hydro Greenn consortium, a consortium of the following executive actors continued: the NAM, Gasunie, New Energy Coalition, the municipality of Hoogeveen and RENDO. Currently a final collaboration agreement is being composed and the preparations are being made for the investment decision so that the new-build neighbourhood Nijstad-Oost can be realised as the first phase of the experiment (IAH10; NAH16). The first stage in the Hoogeveen experiment is not representative because it is a newbuilt neighbourhood and that is not where hydrogen is best to be used. The first stage in the Hoogeveen experiment is however needed for the second stage (NAH8; NAH9; IAH10; RA14).

The experiment is already being planned to be expended. If the use of hydrogen in Nijstad-Oost is successful, the neighbouring existing neighbourhood Erflanden can also switch to hydrogen in the second phase. The neighbourhood Erflanden is currently heated by natural gas and in this phase the existing natural gas network will be used (NAH8; NAH9; IAH10; RA14; NAH16). Doing such an experiment is a way for the municipality and province to put themselves in the spotlight (NAH9). The buildings in Erflanden are built between 1990 and 2020, from which the majority is built between 2000 and 2010 (Allecijfers, 2021a). These buildings are well insulated but not well enough for all-electric solutions or a heating network (IAH10; NAH9; Aué et al, 2020). Furthermore, a heating source for a heating network is available. Insulating the buildings so that they are suitable for all-electric solutions or a heating network would be more expensive then adapting the buildings for the use of hydrogen. Additionally, investments in the infrastructure for a heating network will be more expensive then the adaption of the natural gas network for hydrogen. Which led to the rational for selecting hydrogen as natural gas alternative for the neighbourhood Erflanden (NAH9; IAH10; NAH11; Aué et al, 2020). Quote 2 demonstrates the consideration for choosing a relatively newer neighbourhood to be converted to hydrogen:

We have now opted for buildings that are quite well insulated and heated with a high temperature, and where that last step to fully sustainable is quite difficult to make, or at least that will cost a lot, because then you are working with underfloor heating and you have to insulate extra. (…) So we think that in that capacity it is justified here. Is it representative? Yes, we think so, because you show that it can also be used in such houses". (IAH10)

3.1.4 Conclusion

Both experiments have a different underlying rational for experimentation and are different in terms of comprehensiveness. The experiment in Stad aan 't Haringvliet is an example of a passive niche, as Smith & Raven (2012) indicated. Using hydrogen in Stad aan 't Haringvliet is a natural choice rather than a strategic reason because other alternatives are unsuitable or not an option. The experiment in Hoogeveen is more a form of an active niche, as defined by Smith & Raven (2012). Using hydrogen in Hoogeveen is a more strategic choice because other alternatives could be an option. Using hydrogen in Hoogeveen could be less representative for the areas hydrogen could potentially be used in the future. Based upon the literature review the limited representativeness of an experiment is pointed out as a barrier for upscaling from experiments (Dijk et al, 2018). This difference could influence the extent of how successful each experiment will be. In the next paragraph the second theme will discuss the implications for using hydrogen in the existing natural gas network.

3.2 The possibility of using hydrogen in the existing gas network

This thesis shows that the central question to how successful the experiments will be and how the hydrogen transition in the built environment will develop, is whether the gas network can be used for the transportation of hydrogen.

3.2.1 Possibilities

According to the respondents, it is technically possible to re-use the existing natural gas infrastructure (IAS2; NAS4; IAS5; RA6; NAH9; NAH10; NAH11; NAH16). Earlier experiments in Ameland, Rozenburg, Uithoorn and the Green Village in Delft (IAS2; IAS5) and the research of KIWA & Netbeheer Nederland (2018) have demonstrated that the existing natural gas infrastructure could be re-used for the use of hydrogen. According to the respondents, re-using the existing natural gas infrastructure is potentially a huge possibility for the application of hydrogen in the built environment in the Netherlands because, the Netherlands has a large scale high-quality gas network (NAH9; NAH10 NAH16). If the gas network does not have to be written off with the use of hydrogen, tens of billions can be saved. The re-use of the existing gas network could be an important advantage compared to other natural gas alternatives, such as all-electric solutions or a heat network, where the infrastructure must be adapted. With alternatives such as a heat pump or a heat network, large investments are now required to insulate homes and construct the infrastructure, but after that the monthly costs are lower. With hydrogen, fewer large infrastructural investments are required if it is possible to re-use the existing natural gas network, but the monthly costs will be higher due to the price of hydrogen. When compared to other natural gas alternatives, hydrogen can become the most cost effective option for the built environment in some places (NAH9; IAH10: NAH11). In addition, space is limited in the substrate and it is therefore not possible to replace all the use of natural gas with electricity alone because electricity takes up much more space (NAH9). Furthermore, hydrogen has the advantage that it can be stored, so the reliability and security of the hydrogen energy system can be guaranteed (RA6; IAH10; NAS15).

3.2.2 Uncertainties

It is however still unsure whether the existing natural gas infrastructure will actually be used for the transportation of hydrogen, which is dependant of technical, regulatory, financial and scaling up issues. There are still technical issues that arise from the creation of a new hydrogen chain that is suitable for the built environment. First the experiments encounter the issue of balancing between demand (production) and supply and the role of storage. Because natural gas is used throughout the Netherlands, the national natural gas network functions as a storage buffer when households' demand for natural gas differs. It is unsure whether the entire gas network will become available for the use of hydrogen in the future. Hydrogen in the experiments will only be used on a small scale in local networks, so the network cannot be used as a storage buffer. To guarantee the supply of hydrogen the local system needs to be over dimensioned (NAS4; NAS15). Secondly, converting the gas network to hydrogen is only possible for an entire block or an entire neighborhood (IAH10; NAH16). Third, actors involved in the experiments have a lot of knowledge about using hydrogen in the existing gas network in the built environment but, people outside of the experiment may have less knowledge such as: residents, firefighters, architects and maintenance workers (NAH8; EX1). Finally, it could be questioned whether the application of hydrogen in the built environment is the most logical application of hydrogen, as is illustrated by quote 3 below. Optimal use could first be made of hydrogen in the industry and other sectors where grey hydrogen is already used al lot because there is a shortage of green hydrogen and there are other alternatives for the built environment (NAH11; NAS12; IAS13; RA14), as is demonstrated by quote 3.

"Hydrogen can be an option, but we do not find hydrogen the most logical application. We see hydrogen primarily as an energy carrier for industry and also as a raw material for the industry and ultimately as a way of storing energy and thus balancing the energy system. But you should only start using this in the built environment, in our opinion, when you can supply all those other sectors sufficiently with hydrogen". (NAH11)

Furthermore, there are regulatory uncertainties for the use of hydrogen in the natural gas network. The Gas Act regulates the transportation of natural gas through the national gas network. The Gas Act is a framework of all kinds of agreements, ranging from security of supply to consumer protection. The Gas Act states that only methane-containing gases may be transported through the existing gas network. Currently the Gas Act allows a 0,5% full. mix of hydrogen into natural gas. This makes the application of 100% hydrogen in the natural gas network by the grid operators legally not possible. The Heating Act makes it possible to transport hydrogen through a closed system. If the grid operator would choose to construct a new hydrogen network outside of the regulated part, it would be legally easier than using the existing natural gas network (IAS5; NAH16).

There are also financial uncertainties as is shown by quote 4 below. Green hydrogen is relatively expensive because electrolysers are expensive and there is an efficiency los. The price of green hydrogen is three times the natural gas price. The current tax structures and the cheap natural gas from Russia ensures that green hydrogen will not quickly become cheaper than natural gas. However, if the government would introduce CO2 levies, the price of natural gas will increase. Furthermore, the costs of hydrogen might decrease due to innovation and increase of production. Currently the hydrogen experiments do not have a profitable business case and subsidies from the national government and the European Union are needed (IAS2; NAH8; NAH9; IAH10; NAS12; NAS15; NAH16). The business case for the experiments is not profitable because a local system has to be over dimensioned for the experiments and hydrogen is currently still expensive. But the investments that are being made in the experiments are considered worth it if the potential yield, of adding an option to the sustainable alternatives for natural gas in the built environment, is considered (NAS15). The potential of upscaling is necessary, otherwise it is not realistic to invest in such an innovation (IAS13).

"So you actually have a double challenge. You have the challenge of the fact that hydrogen now is still expensive. You have to oversize a local system. And the third is that you are competing with something that is incredibly cheap, which is natural gas". (NAS15)

Finally, for upscaling it is uncertain to what extent the natural gas grid becomes available for hydrogen. The GasUnie (n.d.) is constructing a hydrogen backbone in the Netherlands which should be available in 2025, see figure 3.1.

Figure 3.1 Gasuni hydrogen Backbone in the Netherlands

Source: Gasuni, n.d.

However, there is no experience with connecting residential grids to this backbone, as is demonstrated by quote 5 below. In the Hoogeveen experiment hydrogen will be supplied by tanker (NAH9; NAH11) and in Stad aan 't Haringvliet hydrogen will be directly produced from wind energy (NAH12). If the use of hydrogen in the built environment were to be scaled up by connecting the grids in the built environment to the national hydrogen backbone, the use of hydrogen in the built environment could become relatively cheaper (NAH9; NAH11; IAS13; NAS15). Furthermore, it is uncertain whether some technical aspects from the experiments are compatible in other places when upscaled. The location of the grid, the grid operator, the production of hydrogen and the types of pipes, couplings and buildings can be place specific. For example, the buildings in Erflanden are from the 1990s-2020s and research has yet to show whether it may also be possible to apply hydrogen in, for example, 1970s buildings (NAH9; NAS4; RA6; NAH8; IAH10).

"Gasunie is working on plans to build a kind of backbone for hydrogen transport throughout the Netherlands. If that basic network is in place, then regional network operators can of course look into whether we can make connections to that infrastructure." (NAH11)

3.2.3 Conclusion

Re-using the natural gas network for hydrogen, is potentially a huge advantage for the use of hydrogen over other sustainable alternatives to natural gas and determines the progress for the hydrogen transition in the built environment in the Netherlands. The potential of using hydrogen in the natural gas network was also pointed out in the literature by Smith et al (2007), Haeseldonckx & D'haseleer (2007) and KIWA & Netbeheer Nederland (2018). If the natural gas network can be used, this will give a boost to the hydrogen transition in the Dutch built environment. It is however unsure to what extent the existing gas network will become available for the use of hydrogen. In the literature Bai et al (2010), van den Heiligenberg et al (2017), Ceschin (2014), Kemp et al (1998) and Naber et al (2017) pointed out that the regime poses regulatory, technical, infrastructural and financial barriers for experiments with innovative techniques. The examining of the case study showed that there are still some technical issues, the Gas Act prohibits the transportation of 100% hydrogen though the natural gas network, using hydrogen in the built environment is not a profitable business case and local factors can differ which means that the scope of the experiments is not fully comprehensive. In the next paragraph the implications for using a new hazardous substance in the built environment will be discussed.

3.3 Using a new hazardous substance in the built environment

Thirdly, this thesis shows that risk acceptation and the extent to which the safety system in the built environment covers the use of hydrogen, determines the success of the experiments and the progress of the hydrogen transition in the built environment.

3.3.1 Risk acceptance

It is important that a balance is found between the risk that is socially acceptable and the possibilities that the application of hydrogen in the built environment offers (IAS5). Striving for a similar risk level for hydrogen as for natural gas is used as a starting point, because the safety risks that are associated with natural gas are socially accepted and demonstrating the equivalent to natural gas gives the application of hydrogen a juridical basis based on the Building Decree (NAH8; IAH10: NAH11; NAH16).

Hydrogen is a different substance then natural gas with different characteristics and therefore the risks of hydrogen are different then the risks involved with natural gas. The main safety risk of using hydrogen in the built environment is that the gas accumulates in a space and that hydrogen can ignite and cause an explosion. The amount of hydrogen and the size of the room play an important role in this. Up to 4 full.% hydrogen, does not ignite, between 4 and 8-9 full.% the ignition of hydrogen is comparable to natural gas and between 10 and 30 full.% hydrogen ignites more easily compared to natural gas. Above 30 full.%, hydrogen is more difficult to ignite. Compared to natural gas, a stronger explosion will occur at a higher concentration of hydrogen (EX1). Furthermore, hydrogen is, just as natural gas, odorless and in contrary to natural gas a hydrogen flame is invisible (NAH8). The use of hydrogen has also safety advantages when compared to natural gas. Hydrogen contains less energy per unit volume, hydrogen evaporates faster and no carbon monoxide can emerge (IAS2).

Research is still ongoing on what measurements can be taken to demonstrate the equivalence of the safety risks of hydrogen to the safety risks of natural gas. To ensure safety, safety measures will have to be taken that are not entirely proportional to the actual risk that there is. So more safety measures must be taken than the difference between natural gas and hydrogen justifies. The bar for safety is set high because calamities with new innovations are devastating (IAS2; NAH8; NAH16). Some measures that are advised to be taken are stated in table 3.3 (NAH8).

Table 3.3 Measurements that are advised to be take inside the building

Odorization of hydrogen	Shut-off valves that prevent a large outflow of hydrogen
Electric cooking, no cooking on hydrogen because of the invisible flame	Ventilation in the meter cupboard and boiler room because in these places there are couplings where leakages could potentially occur
Only using certified installers for the installation of a hydrogen boiler	

3.3.2 The safety system

The current safety system in the built environment does not cover the use of hydrogen. Residents in a hydrogen neighbourhood need to be educated about the safety of hydrogen, fire fighters need to be trained and safety measurements and regulations for hydrogen in the built environment need to be established (EX1; NAH8). The absence and inadequacy of the legislation also makes it unclear who is responsible for supervising the enforcement of safety regulations and due to the lack of experience with hydrogen in the built environment there are no safety standards or NEN norms. NEN norms are included in the Building Decree and are based on practical experience (IAS2; IAH10; NAH16; Ex1; RA14).

There is already a safety system for the use of hydrogen in the process industry, for the transportation of hydrogen and the storage of hydrogen (EX1; NAH8). Hydrogen is already used in the process industry for several years and there are regulations and legislation that regulate the use of hydrogen in the process industry. The process industry also has its own corporate firefighters brigade. However, regulations and legislation from the process industry might not be suitable for the built environment. The process industry uses larger quantities of hydrogen under a higher pressure than that would be used in the built environment. Also, those involved in the process industry are trained for the use of hydrogen, in the built environment the vast majority of residents are not (EX1; NAH8). Additionally, the transport of hydrogen to buildings falls under the Transport External Safety Decree and the storage of hydrogen, such as risk contours and group risks, is already regulated by the External Safety in Establishments Decree (NAH8). In the upcoming Environmental Act safety distances for hydrogen filling stations will be regulated in the Living Environment Quality Decree and architectural facilities in higher risk areas will be regulated by the Building Quality Environment Decree (EX1).

3.3.3 Conclusion

The progress of the hydrogen transition is dependent on if the risks that are involved with the use of hydrogen are socially accepted. This was also pointed out by KIWA & Netbeheer Nederland (2018) and Najjar (2013) in the literature. The aim is to demonstrate with the experiments the equivalence of the safety of hydrogen to the safety of natural gas because the risks involved with the use of natural gas are socially accepted. Hydrogen has different characteristics than natural gas and more research is needed to demonstrate what measurements are needed to demonstrate the equivalence of hydrogen to natural gas. Furthermore, hydrogen needs to be incorporated in the safety system for the built environment. Residents need to be educated, fire fighters need to be trained and regulations for using hydrogen in the built environment need to be drawn up.

3.4 Protected space for the experiments?

For the experiments to be able to continue to develop and to be successful it is important that they are protected. Protection is all the different things that help the experiment to exist and grow despite the existing regime (Kemp et al, 1998; Smith & Raven, 2012). This can range from (adjusting) regulations to financial arrangements such as governmental grants, having a physical space to experiment and having governmental programs for the experiments. This thesis shows that the protection of the residential hydrogen experiments in Stad aan 't Haringvliet and Hoogeveen is vulnerable, which could hinder the development and success of the experiments.

3.4.1 The regulations-experience impasse

According to the respondents, regulations and legislation form the greatest barrier for the application of hydrogen in the built environment. Legislation often lags behind technical innovations because technical innovations happen before their legislation is made. Existing regulations and legislation for the built environment and for hydrogen are currently not adequate (EX1; IAS2; NAS4; RA6; EX7; NAH8; NAH9; IAH10; NAH11; NAS12; IAS13; RA14; NAS15; NAH16). In order to formulate an overarching political vision on which adequate regulations and legislation can be based, more experience with hydrogen is necessary. However, to conduct more experiments to gain more experience, adequate regulations and legislation are needed (NAH8; NAH9; EX7; IAS13). This regulations versus experience impasse is show in quote 6 below. This impasse is partly due to the absence of a clear national hydrogen policy and the inexperienced role and a relatively small municipality (NAH9). Making legislation and regulations adequate is a process that will take years and some legal and regulatory barriers are tackled at European level which makes the process of formulating legislation and regulations even more complex (IAH10; RA14).

"The municipalities would like to see a fully substantiated piece with, indeed, a story showing that we comply with laws and regulations, but the laws and regulations are not yet there. While a committee is working on legislation and regulations, they want to have experience from the field so that they can come up with good legislation. Well that is a bit of the stumbling block we are currently facing". (NAH9)

This impasse shows the necessity of Strategic Niche Management as introduced by Kemp et al (1998). Without creating a protective niche to nurture the innovative experiments with the use of hydrogen in the built environment, the innovation will not progress and will not succeed beyond this impasse as also Kemp et al (1998) and Smith & Raven (2012) pointed out for other innovation experiments.

3.4.2 Experiment specific arrangements

In order to move away from this impasse some experiment specific regulations and arrangements can be made to make the application of hydrogen in the built environment possible for some experiments (IAS2; RA3; NAS4; EX7; NAH8; IAH10; NAH11; RA14; NAS15; NAH16). Protective regulations are a form of active protection, as defined by Smith & Raven (2012), because these regulations are strategically and actively introduced to help the experiment. Legislation is largely used to control risks. Risks can also be managed in different ways, also in experiment specific agreements, only then agreements are not recorded uniformly in legislation (NAH11). An important starting point for making the specific arrangements for the hydrogen experiments possible, is that the equivalence with natural gas is demonstrated (NAH8; IAH10: NAH11; NAH16).

Earlier experiments in Rozenburg and Uithoorn were illegal but were possible because there was a political demand for experiments with hydrogen, the right stakeholders were involved and the experiments were considered to be highly important. Furthermore, there were no residents involved or there was an alternative for if the supply of hydrogen would fail (IAS2). The hydrogen experiment in the Green Village was possible because the Green Village has a special status in which no or other regulations and legislation apply (The Green Village, n.d).

For the experiments in Stad aan ‘t Haringvliet and Hoogeveen, the Crisis and Recovery Act provides the possibility to request room for experimentation on a number of laws, among which the Gas Act. However, the request can be denied by the parliament and the Crisis and Recovery Act will be abolished with the Introduction of the new Environmental Act (RA3; IAH10; NAH16). The upcoming Environmental Act, will not change the regulation and legislation situation for the use of hydrogen in the built environment (EX1; NAH8). Furthermore, some ministries have the power to determine temporary policies (IAH10). Additionally, the Program Natural Gas Free Neighbourhoods does not give their experiments a special status which would except the experiments for certain laws and regulations. The Program Natural Gas Free Neighbourhoods experiments are asking for a special exception status for certain regulations, but that is very tensive from a political point of view, because if things go wrong, responsibilities are not laid down by law. Hence, there is a tendency to calculate risks completely, as is show by quote 7 below. The Program Natural Gas Free Neighbourhoods, among other things, collects barriers encountered by the experiments and puts them on the agenda of among others, the parliament. Solving the barriers is usually beyond the scope of the program. For example, new regulations or adjustments to existing regulations are not implemented within the program. The responsible ministries are responsible for the formulation of new regulations or adjusting existing regulations (RA3).

“The [Program Natural Gas Free Neighbourhoods] *experiments sometimes ask for experimental freedom. If you really have an experimental program then you must give room for experimentation, so that they do not have to follow a number of laws. Yes, politically that is always super tentative, because if it goes wrong then who is responsible? So the inclination is to calculate everything”.* (RA3)

The urgency of making legislation and regulations sufficient for the use of hydrogen in the built environment has now also reached The Hague. Therefore, a Green Deal has been concluded with the ministries of EZK, BZK and IenW, the province of Drenthe and Zuid-Holland, the municipalities of Hoogeveen and Goeree-Overflakkee, the grid operators and the NVDE to define and resolve the legislative barriers. Also, several partners were incorporated such as the Safety region, local entrepreneurs and knowledge and educational institutes (Rijksoverheid, 2021; IAS2; RA6; NAH10; IAS13; NAS15; NAH16). With the Green Deal, an exceptional position could be created for Stad aan 't Haringvliet and Hoogeveen where, within a defined location and time, different or no laws and regulations apply (IAS2; RA6). Most concrete details of the use of hydrogen in the built environment are already known from experience with hydrogen in the industry and from experience with natural gas in the built environment, which means that temporary arrangements can be made based on the existing knowledge (NAS15). To guarantee safety, extra safety measures can be included as a condition in the temporary regulations (NAS15; NAH11). Regulations and legislation can then be drawn up on the basis of the results obtained from Stad aan 't Haringvliet and Hoogeveen. These experiments are therefore highly influential on national policy (IAS2; NAH11; IAS13; RA14).

3.4.3 Vulnerabilities

This thesis shows that the potential exceptional position that the Green Deal potentially can give the experiments is however fragile for opponents to challenge the execution of the experiments due to the lack of a political and juridical foundation. Not much position has yet been taken in national politics about hydrogen. The national politics have not been about whether hydrogen in the built environment will be used (RA3). It then becomes uncertain whether to invest in hydrogen experiments (IAS2; RA3;

NAH4; IAS5; RA6; NAS12). For example, biomass was first regarded by national politicians as a solid sustainable technique, but the technique was rejected later. Experiments that focused on biomass had to start all over again with a new technique (RA3). Furthermore, the Gas Act gives residents the right to maintain their natural gas connection. If a resident does not want to participate, the resident is in his right and the conversion of the block or neighborhood cannot proceed. This makes the position of the experiments difficult (RA3; RA6; NAH16), as is illustrated in quote 8:

"If people do not want to participate, they eventually, if we have to be free of natural gas by 2050, have to be disconnected at some point in time. So we say we're going to seduce everyone and try to get everyone along, but there are always a few who will say: the house will be just as warm and it won't cost me anything, but I still want to stay on natural gas. At some point you have to be able, just to prevent high costs for society again, to disconnect people. The moment in time you will do that in the process, is politically very tensive. In the Parliament they think of these people as votes. But if you want to achieve the objective, then you have to be able to do something. The municipality cannot do that at the moment. So they say yes, we can try to seduce people, but if people don't want to, I have to arrange a gas connection for those people, because that's just the law." (RA3)

To stimulate the support among the residents in the experiments, residents are involved in everything and can participate (ISA2; NAS4; IAS5; NAH8; IAH10; NAS15; NAH16). In both experiments there is residential support but it is fragile, especially in Hoogeveen communication towards the residents could be better (NAH9). Support among residents depends on all kinds of factors such as affordability, reliability, safety, hassle aversion and aversion to the energy transition (NAH16). Also, the national natural gas free debate affects the application of hydrogen in the built environment (RA6; RA14). Making the built environment free of natural gas has gained momentum since it was decided to use less gas from Groningen. But the speed with which the built environment is being made natural gas free can cause social resistance (RA14). Furthermore, it is expected that there will always be residents who prefer to keep the status quo (RA6). Unknown makes unloved and residents can experience a NIMBY feeling (EX1). A public acceptance study from 2006 showed that generally there is support for using hydrogen in the built environment in the Netherlands: 94% of respondents are generally willing to use hydrogen in their house if it is equivalent to the use of natural gas. When there is an increased risk with the use of hydrogen 61% of the respondents were willing to use hydrogen (Zachariah-Wolff & Hemmes, 2006). Residential support is however place specific and could also form a barrier for upscaling the use of hydrogen in the built environment (NAS4; IAH10).

Currently, municipalities have limited powers to force residents to participate in their plan to heat the built environment with a natural gas alternative which is a barrier to experiments with natural gas alternatives. When this changes, making the disconnection of residential natural gas connections no longer illegal for municipalities, is politically very tensive. The freedom of choice is highly regarded and freedom of choice is difficult to combine with any possibility of making the disconnection of natural gas mandatory. A mandatory closure must be a careful consideration between the social importance of the energy transition and the individual freedom of residents (RA3; RA6; NAH16). In the upcoming new Energy Act this forced disconnection is made possible. The Energy Act updates and merges the Electricity Act and the Gas Act and is a step in removing the regulatory barriers, but there is still a lot of uncertainty about this act (RA14; NAH16).

Additionally, experiment specific arrangements are not always suitable as generally applicable laws and regulations (RA6; EX7). For the upscaling of the use of hydrogen in the built environment it is necessary that the political vision is clear and that legislation and regulations are adequate (NAH11). For example, making the disconnection of residential natural gas connections possible could help the current experiments. However, in a later stage the natural gas grid could potentially be used for the upscaling of the use of hydrogen in the built environment. So the experiments might be doing something that help early experiments but hinders next steps.

3.4.4 Conclusion

This thesis shows that the extent to which the experiments are protected will determine their success. In the literature Kemp et al (1998), Smith & Raven (2012) and Geels (2019) point out the importance of a protecting niche in which experiments can take place. Without a protective niche innovations are likely to be unsuccessful. The protective niche for the Stad aan 't Haringvliet and Hoogeveen experiments is fragile. The Gas Acts gives residents the right to refuse to participate which would stop the experiments from being developed further. This touches on the debate between the freedom of citizens and the legal certainty for the energy transition.

Just protecting the experiments might not be enough as at a certain point for the experiments to become successful, where the practices can be upscaled, it is necessary that the experiments transform the regime. Based on the conceptualisation of upscaling from experiments by Smith & Raven (2012), experiments can be made 'fit and conform' with the regime or the experiments can 'stretch and transform' the regime. A fit and conform strategy for hydrogen would entail that the use of hydrogen in the built environment is arranged according to the selection criteria of the current energy system. This would mean that only up to 0,5% full. hydrogen can be mixed into the natural gas grid and that residents keep their right to remain connected to the natural gas grid. This would limit the success of the residential hydrogen experiments and their contribution to the energy transition. A stetch and transform strategy for the use of hydrogen in the built environment would involve changing the current energy system. With this strategy the regulations regarding the use of hydrogen in the built environment would be adapted based on the knowledge and experience gained from the experiments. By introducing the practises from the experiments in the regime, the regime is destabilized and can be transformed.

Conclusion & Discussion

Due to climate change the Dutch government is looking for alternatives for fossil fuels in the energy system. Indeed there are many good reasons to consider hydrogen in this energy transition. The built environment is an interesting sector were hydrogen could potentially be used. Residential (Hydrogen) experiments are emerging as an important part of the Dutch gas free strategy. Planning these experiments remains a challenge for several reasons. I have studied concrete examples of hydrogen residential experiments in the Netherlands to answer the proposed research questions.

Regarding the first sub question, I examined: *what theoretical barriers were expected to hinder the development of experimental hydrogen neighbourhoods*. I found three specific barriers for using hydrogen in the Dutch energy transition. First, based on Detz et al (2019); Dincer (2012); Smith et al (2007); Jempma & van Schot (2007) and KIWA & Netbeheer Nederland (2018), technique & costs can provide the following barriers: green hydrogen is still relatively expensive as compared to grey hydrogen and the natural gas grid seems adequate for the use of hydrogen but for the large scale application unforeseen costs and issues could emerge. Secondly, based on KIWA & Netbeheer Nederland (2018); Kim & Moon (2008); Gandia et al (2013); Sherif et al (2005) and Najjar (2013), safety could form a barrier when using hydrogen is more dangerous than the use of natural gas, something that still remains unclear. Safety perception and risk acceptation of residents are important factors that could form a barrier. Finally, based on Bakhuis (2020) and Detz et al (2019), policy & regulations can form a barrier. The absence of a clear vision on the use of hydrogen and adequate regulations could hinder actors to become involved and to invest. This could hinder further experimentation with hydrogen in the built environment.

Regarding the second and the third sub question, I examined: *if the current experimental hydrogen neighbourhoods in Stad aan 't Haringvliet and Hoogeveen are successfully addressing the barriers and opportunities that are experienced and how the experienced barriers and opportunities can be addressed to upscale the development of hydrogen neighborhoods*. I found four key themes that propose barriers and opportunities for the experiments and determine the success and the possibilities to upscale the development of hydrogen neighbourhoods. First, the underlying difference in rational for experimentation and the comprehensiveness of the experiments could affect the extent to which the experiments are successful. Using hydrogen in the Stad aan 't Haringvliet experiment was a natural choice since other natural gas alternative were unsuitable or not an option and the buildings in Stad aan 't Haringvliet are illustrative for where hydrogen can best be used. With the Hoogeveen experiment it is possible to use other natural gas alternatives and the buildings are less representative for where hydrogen can best be used. This makes to rational for using hydrogen in Hoogeveen more strategical. Secondly, both experiments assume the possibility of using hydrogen in the existing gas network, which provides the usage of hydrogen huge financial and technical advantages over the use of other natural gas alternatives. However, there are technical, regulatory and financial uncertainties to this which the experiments are currently not addressing. For example, the experiments are assuming that the natural gas grid can be used to upscale the use of hydrogen, however this is not included in the experiments. Third, for the usage of a new hazardous substance in the built environment with both experiments, the acceptance of the risks involved needs to be evaluated and hydrogen needs to be incorporated within the safety system. Examining safety measure is included in the experiments, but examining risk acceptance is not currently addressed. Finally, the protection of the experiments is fragile. Protection is needed to overcome the regulation – experience impasse. The Green Deal can provide some sort of a protective space but this has not yet been established and even if such a protective space would be created, the space could be challenged on the basis of the Gas Act. The Gas Act will be changed with the upcoming Energy Act, but this goes with uncertainty and is political tentative. The protective space is not something that the experiments continuously address and could hinder the further development of the experiments. For the development of hydrogen neighborhoods to be upscaled, the experiments need to actively address these issues.

With the knowledge gained from the sub questions the main research question can be answered. To contribute to the progress of the hydrogen transition in the Netherlands I examined in this thesis: *How barriers and opportunities set by the socio-technical regime are experienced with the development of experimental hydrogen neighbourhoods in Stad aan 't Haringvliet and Hoogeveen.* The experiments are not fully addressing all barriers and opportunities with could hinder the success of the experiments and the progress of the hydrogen transition in the Netherlands. The barriers and opportunities are not fully addressed because stakeholder within the experiments are not aware of all the barriers and opportunities and how these can hinder or benefit the experiments. Furthermore, the experiments focus mainly on examining how a residential hydrogen neighbourhood can be established but they divert attention from other possible barriers that can hinder their development.

Planning implications

From a transitions and innovations perspective the residential hydrogen experiments in Stad aan 't Haringvliet and Hoogeveen could progress a transition towards the use hydrogen in the built environment. However, from a planning perspective there is not enough certainty for those involved in the planning system to realise this technology because knowledge and a political vision are missing. The progress of the hydrogen transition is dependent on the extent to which the use of hydrogen is incorporated in existing planning instruments, such as the transition vision heating and instruments of the Environmental act such as: environmental vision, environmental plan, program's and environmental permits. It is important that the use of hydrogen is incorporated in these plans because hydrogen developments and other spatial developments need to be coordinated. For example, removing the natural gas grid in some neighbourhoods could hinder a later transition towards hydrogen. It is to be expected that cities and villages in the Netherlands do not have to be planned differently because hydrogen can possibly replace the function of natural gas which is already embedded in the energy system in the Netherlands. For planners to incorporate hydrogen in existing planning instruments, planners need to know about the potential of hydrogen. If planners do not know this, it is likely that the use of hydrogen will not be incorporated in the planning instruments because planners will chose for techniques with which they are familiar and there is clarity about, such as all-electric solutions. This brings the risks that even if the experiments in Stad aan 't Haringvliet and Hoogeveen are successful, hydrogen will only be used in a few cases and that an overall transition towards the use of hydrogen in the built environment will come to an end. It is therefore recommended that more research is done on planners knowledge of the potential of the use of hydrogen in the built environment.

Limitations

For this research I used a transitions and innovations perspective to the development of residential hydrogen experiments. In particular I used the Strategic Niche Management approach. From origin the SNM approach focusses on creating a protective niche and internal niche processes (Kemp et al, 1998). For examining constraining barriers for experimentation the multi-level perspective, introduced by Geels & Kemp (2000) was useful to understand niche – regime relations and regime barriers. Furthermore the research of Bai et al (2010); van den Heiligenberg et al (2017); Naber et al (2017); Ceschin (2014) and Dijk et al (2018) was useful to identify different constraining barriers but was also limited generic types of barriers. With this research I showed that the extent to which a niche protects innovative experiments is not always binary, a niche is protected or not, as Kemp et al (1998) and Smith & Raven (2012) suggested. The Stad aan 't Haringvliet and Hoogeveen experiments are protected but their protected space is fragile and easy to challenge. Due to the fragile protected space the experiments are not fully exposed to the constraining barriers set by the regime but they are also not fully protected. It is recommended that more research is done on the nonbinary state of protected spaces for experimentation.

This research is limited to the examination of two residential hydrogen experiments in the Netherlands. It is recommended that research is conducted on barriers constraining other residential hydrogen experiments in the Netherlands and abroad. Furthermore, a selective number of informed respondents that are proponents of the hydrogen transition are interviewed for this research. It is recommended that more interviews are conducted with planners, residents and opponents of the hydrogen transition, or who are not informed of the use of hydrogen and who are also outside of the experiments.

The COVID-19 pandemic posed some limitations for this research. Interviews could not be conducted face to face, which could have limited interpretations and understandings, I could not be a part of the experiments and focus groups with the residents were not possible.

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Appendix 1: Compound interview guide in Dutch

<u>Rol organisatie/ respondent</u>

- Wat is uw functie binnen uw organisatie?
- Wat is uw functie binnen het project?
- Hoe is het project tot stand gekomen?
    - Van wie was het initiatief?

<u>Barriers & oplossingen</u>

- Techniek
    - Vormt de huidige technische kennis en mogelijkheden een barrière voor het toepassen van waterstof in de gebouwde omgeving?
        - Is er voldoende groene waterstof beschikbaar?
        - Zijn er voldoende mensen opgeleid voor de toepassing van waterstof in de gebouwde omgeving?
        - Hindert of faciliteert de bestaande infrastructuur de ontwikkeling?
- Veiligheid
    - Vormt veiligheid een barrière voor het toepassen van waterstof in de gebouwde omgeving en binnen de woning?
- Wetgeving & beleid
    - Vormt wetgeving een barrière voor het toepassen van waterstof in de gebouwde omgeving?
        - Leidt de ontoereikendheid van wetgeving en beleid voor waterstof in de gebouwde omgeving tot terughoudendheid actoren en investeerders om betrokken te raken bij pilots?
        - Belemmerd de geringe kennis en ervaring met waterstof in de gebouwde omgeving het vormen van wetgeving en beleid?
        - Kan industrie wetgeving ook op gebouwde omgeving worden toegepast?
        - Heeft het project een speciale status waardoor het project uitgezonderd is van bepaalde regels en worden en specifieke afspraken voor het project, zoals bijvoorbeeld de Green Deal?
        - Regelt de nieuwe Energie wet/ Omgevingswet het gebruik van waterstof in de gebouwde omgeving?
- Financiering
    - Vormen kosten een barrière voor het toepassen van waterstof in de gebouwde omgeving?
        - Is het toepassen van waterstof in de gebouwde omgeving een rendabele business case?
        - Is er veel subsidie nodig voor waterstof projecten?
        - Is er voldoende betaalbare groene waterstof beschikbaar?
        - Leidt het gebruik van het bestaande aardgasnet tot kosten besparing?
        - Zou er een functionerende waterstof markt kunnen ontstaan?
        - Wordt het rendabeler naar mate er op grotere schaal gebruikt gemaakt wordt van waterstof voor het verwarmen van woningen?
- Samenwerking
    - Vormt samenwerking een barrière voor het toepassen van waterstof in de gebouwde omgeving?

        - Zijn alle betrokken partijen vertegenwoordigd in de samenwerking?
        - Wordt de samenwerking bemoeilijkt door de betrokkenheid van veel verschillende actoren?
- Draagvlak burgers
    - Vormt draagvlak onder burgers een barrière voor het toepassen van waterstof in de gebouwde omgeving?
- Zijn nog andere barrières volgens u voor het gebruik van waterstof in de gebouwde omgeving?

<u>Opschalen</u>

- Als waterstof in de ene wijk toegepast kan worden, kan het dan ook in andere wijken toegepast worden? Of is dat heel situatie specifiek?
    - Wordt er ingezet op representativiteit en het creëren van blauwdrukken?
- Wat zou er moeten gebeuren, zodat waterstof op groter schaal in de gebouwde omgeving toegepast kan worden?
    - Welke Barriers voorziet u hierbij? Hoe kunnen deze aangepakt worden?

Heeft u nog een aanvulling waar nog niet naar gevraagd is?

Appendix 2: Codes used in the interview summaries

- General information about the respondent/ institution/ organisation
- Safety
- Regulations and legislation
- Policy
- Finance
- Technique and infrastructure
- Representativeness
- Political vision
- Collaboration
- Residential support

Appendix 3: Original quotes in Dutch

Quote 1:
"Het is een bottum up initiatief, de bewoners hebben op een gegeven moment gezegd in 2017 wij willen eens kijken wat er mogelijk is op het gebied van de energie transitie, (…) en hebben we de eerste analyses gedaan en als je dan (…) naar het dorpje Stad aan 't haringvliet kijkt, waar geen hoogbouw is, waar geen rest warmte in de buurt zit, waar het heel erg lastig wordt om naar een laagtemperatuur verwarmingssysteem te brengen, het is allemaal vrij staande individuele woningen die toch slecht tot zeer slecht geïsoleerd zijn, ja dan is een duurzaam gas is wellicht de enige oplossing maatschappelijke gezien, ja toen is ook waterstof op een gegeven moment genoemd en op dit moment zijn de bewoners worden mee genomen in het proces, een volwaardig project partner ook samen met een hele hoop andere partijen dus komt uiteindelijk van de bewoners en het loopt al jaren."

Quote 2:
"Wij hebben nu hier gekozen voor woningen die, die best wel goed geïsoleerd zijn en dan wel met hoge temperatuur worden verwarmd en waar die laatste stap naar volledig duurzaam vrij lastig is te maken, of in ieder geval dat gaat, dat gaat heel veel kosten, omdat je dan met vloerverwarming aan de gang en je moet nog extra isoleren. (…) Dus wij vinden dat in die hoedanigheid hier verantwoord. Is het aan representatief? Ja wij denken van wel, omdat je aantoont dat het ook in dergelijke huizen toepasbaar is".

Quote 3:
"Waterstof kan wel een optie zijn, maar we vinden niet de meest logische toepassing waterstof. Wij zien waterstof vooral als de energiedrager richting de industrie en ook als grondstof voor de industrie en uiteindelijk als manier om energie op te slaan en daarmee energiesysteem te balanceren. Maar gebruik in de gebouwde omgeving dat, zou je wat ons betreft pas moet gaan doen, op moment dat je al die andere sectoren voldoende kan voorzien van waterstof."

Quote 4:
"Dus je hebt eigenlijk een dubbele uitdaging. Je hebt de uitdaging van het feit dat waterstof nu gewoon nog duur is. Je moet een systeem lokaal over die over dimensioneren. En de derde is dat je concurreert met iets wat waanzinnig goedkoop is, namelijk aardgas".

Quote 5:
"Gasunie is bezig met plannen om een soort backbone voor waterstof transport door heel Nederland aan te leggen. Als dat basis netwerk er is kunnen vervolgens regionale netbeheerders natuurlijk kijken van kunnen wij aansluitingen maken op die infrastructuur".

Quote 6:
"De gemeentes die willen graag een onderbouwd stuk zien met inderdaad een verhaal waaruit blijkt dat we voldoen aan wet en regelgeving maar de wet en regelgeving is er nog niet. Terwijl daar een commissie wel mee bezig is met wet en regelgeving, daar het een en ander voor op te tuigen, die willen graag ervaring hebben vanuit het veld zodat zij tot goeie wetgeving kunnen komen. Nou ja dat is nu een beetje het struikelblok waar we mee zitten".

Quote 7:
"Daar vragen die proeftuinen ook wel al af en toe om, als je echt een experimenteer programma hebt dan moet je ook gewoon ruimte geven om te experimenteren, dus dat ze een aantal wetten niet zouden hoeven volgen. Ja dat is politiek gezien altijd super spannend, want als het dan mis gaat wie is dan de gene die heeft gedaan? Dus de nijging is om vervolgens alles door te berekenden."

Quote 8:
"Als mensen niet mee willen doen, dan moet je ze uiteindelijk als we in 2050 aardgas vrij moeten zijn, moeten ze op een gegeven moment toch afgesloten worden. En dan proberen we te zeggen we gaan iedereen verleiden en proberen mee te krijgen, maar het zijn er altijd een paar die zullen zeggen: het is net zo warm en het kost me niks, maar ik wil op gas blijven. Op enig moment moet je kunnen zeggen, ook om weer hoge kosten voor de maatschappij te voorkomen, we gaan er gewoon mensen afsluiten. En op welk moment je dat op het proces doet, is politiek natuurlijk super spannend en in de tweede kamer denken ze dan het zijn allemaal mensen die kunnen op mij stemmen. Maar als je de doelstelling wil realiseren, dan moet je op een gegeven moment ook iets kunnen en dat kan de gemeente nu niet. Dus die zeggen ja we kunnen verleiden tot we een ons wegen, maar als mensen niet willen dan moet ik als nog een gas aansluiting voor die mensen regelen, want dat staat gewoon in de wet."