# The transition enabling effect of launching customers in the energy transition of Dutch shipping; what the Rijksrederij can contribute.

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# The transition enabling effect of launching customers in the energy transition of Dutch shipping; what the Rijksrederij can contribute

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Performed at

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# Summary

The Dutch shipping cluster will have to make a radical systemic transition from a fossil fuel based to a climate neutral based socio-technical regime in order to stop its contribution to climate change. Elements such as technology, infrastructure, regulations, user practices and mindset will all have to adapt. The transition requires the dedication and commitment of many actors, such as shippers, shipping companies, shipyards, ports, classification societies, governments, etc. This makes the transition complex, especially since the sector is characterized by a wide variety of ship types, operations, organizations and operational areas with a complex governance structure. Furthermore, the price and performance of climate neutral alternatives is still uncertain but does not appear to lead to a competitive business case. There are thus major transition barriers that disable a transition to a climate neutral shipping sector.
The Rijksrederij (governmental shipowner of the Netherlands) has the goal to be climate neutral by 2030, despite the transition barriers. This will make them launching customer of many innovative climate neutral shipping practices, which is an opportunity to further develop them. The Rijksrederij could thereby enable other actors in the shipping cluster to make a transition, which can lead to major environmental benefits since it will shorten the transition timeline. This thesis aims to identify the transition barriers, required transition enablers and the role of a launching customer in the energy transition of Dutch shipping. A focus was placed on pilot projects, since these will be the first step of the transition of the Rijksrederij.

Using the socio-technical transitions theory as a framework, literature on transition barriers, enablers, pathways, and maritime specific aspects was evaluated as a starring point. A qualitative approach was applied, which consisted of 13 semi-structured interviews with industry experts. The interviewees had a variety of functions in decision making roles at a wide range of organizations. The interviews were analysed using Atlas-TI to categorize and label the input. A detailed and holistic description of the transition barriers, transition enablers and pilot projects could be created by combining the knowledge from the interviewees. Based upon three case studies of pilot projects, verification of the obtained knowledge and additional depth, detail and context was obtained.

It was found that the main transition barriers are a consequence of interdependency, commercial infeasibility, uncertainty, the required assets, regulations and mindset of the actors. The shipping value chain typically has eight different parts, a transition of just one vessel depends on close cooperation between the parties that deliver them. These actors are generally commercial businesses that require a balance between investment, expected return and risk. However, the costs of climate neutral sailing do not outweigh the benefits and there are significant risks due to uncertainty in future price, performance, availability, reliability and other characteristics of both technology and climate neutral energy carriers. These barriers are strengthened by the required assets that are capital intensive and have a lifetime of multiple decades, over which reliable performance is demanded. This, combined with fierce competition, makes actors risk averse and focus on their own link in the chain where they see limited possibilities to contribute to the transition, especially since the financial position of many actors is currently weak. Then there are also market entry barriers for climate neutral sailing since regulations for classification and operation are based on the established fossil fuel practices.
Four transition enabling developments were identified that can together create a pathway past the barriers: niche development, pressure and support from the landscape, reorientation of actors and the articulation of expectations and vision on climate neutral sailing. Niches are spaces in the cluster were the transition barriers are less pronounced, as a result of unique characteristics. For example, governmental ship owners with no commercial focus such as the Rijksrederij. This enables actors to develop

radically different sailing or financing practices, they are therefore seen as the seeds for systemic change. The landscape is the exogenous context to the shipping cluster which includes politics, societal opinions, fuel prices and economic developments. The Landscape can put pressure the regime to make a transition and support niches to make them gain momentum, for example by implementing a fuel levy or granting subsidies. These two processes can lead to a reorientation of cluster actors who will than change the course of their development trajectory towards adopting niche practices, which will again stimulate niches and landscape developments. The current uncertainty slows these three developments down, since significant commitment and investments are risky. However, these very developments are also necessary to take the uncertainties away. A launching customer can play a crucial role in developing the niche and articulating visions and expectations.

It is found that pilot projects provide a practice-based learning method of doing, using and interacting in which actors from across the value chain can receive feedback on their ideas and designs. This is perceived as crucial for innovation by both ship production experts and literature since it aligns with the innovation process of low-quantity products. It will contribute to the articulations of visions and expectations and attract more resources, which makes the niche gain momentum by enabling scale-up, follow-up and spin-of projects. It was reasoned that pilot projects can optimize their value by implementing five management tips. First: establish long term close cooperation between actors from across the chain to deal with teething problems and co-evolve by learning processes, for example in a consortium. Second: make clear agreements on who is responsible for which part of the project to avoid conflicts during the risky, long and multidisciplinary development process. Third: focus on scalable energy carriers, technologies and infrastructure that have not been fully developed, to provide transition enablers for the benefit of many actors and increase the chance of follow-ups and spin-offs. Fourth: share the results and workload of a pilot to create synergy between projects, minimize the workload, develop shared practices and attract more resources. Fifth: actively promote all outcomes to reorient regime actors in the right direction and attract resources.

Launching customers start a demand for climate neutral technologies, infrastructure, energy carriers, regulations, and services which can lower the transition costs for other actors and thereby enable them to make a transition. The case studies provided examples were a pilot can lead to over 50% reduction in the extra CAPEX for climate neutral sailing for a direct follow-up. OPEX reductions strongly depend on the energy carrier, operational area and created demand. Examples where found of up to 100% reduction of the extra OPEX for climate neutral sailing. This is possible since the energy carrier can be produced in the local area and the demand is stable and substantial capital intensive investments are made. Launching customers can thereby reduce the marginal abatement costs (MAC) of greenhouse gasses for other actors by tens of percent. The MAC of sailing on climate neutral alternatives is approximately €400 on average, which is too high for almost all actors in the cluster. A reduction can make a transition possible for a larger group, who can again reduce the costs. Launching customers can thereby set the adoption in motion. This adoption is likely to take decades due to the lifetime of the assets and the MAC reduction that is necessary for a cluster wide transition.

It can be concluded that the Rijksrederij is in a unique position for launching customership due to their non-commercial nature, local operations, transition goal and opportunity of obtaining large public funds without distorting the level playing field in the sector. Furthermore, they have over 100 vessel of various types that cover the entire Dutch operational area, which means that their transition enablers will reach the entire Dutch operational area and various vessel types. Many of their vessels are at the end of their lifetime and need to be replaced anyhow. A transition will now in many cases lead to more than a doubling of the yearly expenses. This thesis provided a substantiated overview of both the origin of these extra costs and ways to bring them down. These depend on many parties but launching customers are clearly a strong driver behind transition enabling developments. The Rijksrederij can be one of the very few parties that are able to accept the current transition costs bring them down, due to their special position in the cluster. The shipping energy transition will be a gradual process of decades, due to the lifetime of the assets in the cluster and the transition barriers. Every development that can shorten this is of great value to the Dutch society, since climate change is a societal problem. It is therefore recommended that the Dutch government increases their support to the transition goal of the Rijksrederij, since there is currently no funding for this transition project that has so much potential.

# Preface

During my study at the TU Delft I spend a lot of time pursuing my dreams of winning the most prestigious rowing races rather than fully committing to my study. When the covid-19 pandemic hit I was still training 11 times a week for the 2020 season, which was eventually entirely canceled. As a result, I completely shifted my focus to starting my thesis, which I liked surprisingly well despite working from home due to the pandemic. It was challenging at times due to covid restrictions, the research approaches I had little experience with and the sudden shift in focus from rowing to studying. Fortunately, I feel like I have overcome these challenges and I am proud of the thesis that lies before you.

My research focuses on the transition to a sustainable shipping sector. I see this as an urgent matter and was eager to make a contribution. It is clear that the transition will be a complex process with many challenges along the way, but I am convinced that there is simply no other way that will lead to a pleasant future. This is important to keep in mind when discussing the challenges of an energy transition, as I do in this thesis. Although a transition does not always seem attractive, it is the only option and I believe it is possible. An inspiring biologist puts it like this:

> “Ten thousand years ago as hunter-gatherers, we lived a sustainable life because that was the only option. All these years later, its once again, the only option.”
> - David Attenborough

I want to thank everyone that has helped me during my master thesis, I could not have achieved these results without you. I feel that the last 8.5 months have been the most valuable part of my studies, for which I must thank my supervisors. First of all my daily supervisor Jurrit Bergsma who has taught me so much about the energy transition of shipping and doing research in general. I feel lucky to have had a daily supervisor who was available and motivated to invest time and effort in providing me with feedback. I would like to thank Bas de Sonnaville for providing me with this interesting research case and the pleasant cooperation during the parts of the research that involved the Rijksrederij. I would like to thank Jeroen Pruyn for his valuable and interesting feedback on my research progress. I enjoyed the feedback sessions and found the cooperation in general very pleasant.

I would like to thank all the participants to the semi-structured interviews for their contributions to this thesis and my knowledge about the energy transition in general. I enjoyed talking to experts in the field and was pleasantly surprised by the helpful attitude. I would also like to thank all the participants of the case studies that provided additional depth, detail and context to my research. I found the people from Lauwersoog, CMB and Loek Verheijen from the Rijksrederij all inspiring to talk with and feel that you are of great value for the energy transition. Your passion, commitment and skills are appreciated.

Finally I would like to thank my family, friends and girlfriend who supported me during the research and made working from home a pleasant experience. A special thanks to my mother who introduced me to qualitative research methods such as Atlas.Ti. Another special thanks to Jente for helping me with the green wave on the title page. And last but not least a special thanks for my girlfriend Roos for finding many spelling mistakes and supporting me throughout my research process.

*L.C. Stolper*
*Delft, December 2020*

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# List of Abbreviations

| | |
|---|---|
| **CAPEX** | Capital Expenditures |
| **CMB** | Compagnie Maritime Belge |
| **DUI** | Doing, Using and Interacting |
| **FC** | Fuel Cell |
| **GHG** | Green House Gasses |
| **IRL** | Integration Readiness Level |
| **IMO** | International Maritime Organization |
| **I&W** | Infrastructure and Water management |
| **MAC** | Marginal Abatement Costs |
| **MDO** | Marine Diesel Oil |
| **MLP** | Multi-Level Perspective |
| **OPEx** | Operational Expenditures |
| **PERT** | Program Evaluation and Review Technique |
| **PM** | Particulate Matter |
| **SNM** | Strategic Niche Management |
| **SRL** | System Readiness Level |
| **STI** | Science, Technology and Innovation |
| **TRL** | Technology Readiness Level |

# Chapter 1

# Introduction

Shipping has run on carbon-based fuels since the transition from sailing ships to coal powered steamships in the nineteenth century. In the twentieth century another transition took place from these coal powered to diesel powered ships, which is still the prevailing energy source. Nowadays marine diesel engines emit over 1 billion tons of CO2 per year, which is approximately 3% of global CO2 emissions (IMO, 2020b). It has been established that these CO2 emissions cause climate change with disastrous consequences, which puts pressure on the sector to make another transition to a climate neutral energy carrier. However, climate neutral sailing is currently still complex and expensive, which leads to numerous transition barriers. Actors that are able and willing to invest in a transition will be scarce, but also crucial for the developments that remove transition barriers. This thesis provides a holistic overview of the transition barriers, required enablers, resulting pathway and specifically the added value of launching customers and their pilot projects for the energy transition of Dutch shipping.

This introduction will start with background information regarding the problem and the Rijksrederij, this is followed by the problem definition and the research objective. The chapter concludes with the initial plan of approach which will be elaborated in chapter 3.

## 1.1 Background information

The shipping sector is important for the Netherlands generating by 3.1% of the GDP and providing 2.85% of total employment. Unfortunately, the sector also generates 3.96% of national yearly CO2 emissions (CBS, 2020; Bossche et al., 2020). Vessels are used for a wide variety of operations such as fishing, dredging, recreation, security or the transportation of goods. It is therefore crucial that the shipping sector makes an energy transition without losing its operational or competitive capabilities. Especially since some of these operations are vital to society.

The large variety in operations requires a large variety in vessels, especially given the differences between inland and open sea operational areas. There is also a variety in organizations that are active in the shipping sector, such as shipowner, shipyards, ports, engineering firms, technology suppliers, energy suppliers and financial institutions. A transition requires all of them to adapt to the new energy carrier with additional technology, infrastructure, user experience, market value, regulations and mindset. This will be a complex process since many elements are interdependent. Everything is tuned to sailing with diesel which creates resistance for change, which leads to a lock-in of the established fossil fuel based sailing practices (Geels, 2002).

The operational experience with sailing on climate neutral energy carriers is currently limited and the development trajectories are uncertain and depending on many criteria (Hall et al., 2018; Bouman et al., 2017). A transition to a climate neutral energy carrier is also likely to lead to lower operational performance and higher costs (Geels, 2011). This might be the reason that CO2 emissions from shipping on Dutch waters have not yet decreased over the last 20 years as can be seen in figure 2.8. The transition is thus at an early stage in which only a few pilot vessels have made the transition to fully climate neutral sailing, while the transition in other transport sectors is accelerating. For example, the amount of cars that can be electrically charged grew by 140% in 2019 to a total of almost 200000 (CBS, 2020).

A transition therefore appears to be particularly unattractive or infeasible for the shipping sector.
The International Maritime Organization (IMO) has set out the goal for the sector to reduce the total annual greenhouse gas emissions by at least 50% in 2050, compared to 2008 emissions (IMO, 2018). This is not yet an incentive to start making the transition since it is so far away and the required emission reduction is limited. However, some countries and organizations are more ambitious and are planning to reduce their emissions significantly sooner, such as the Dutch governmental shipowner which has the goal to become climate neutral in 2030. This organization, called the Rijksrederij, would thereby become an innovator or early adopter as defined in figure 1.2. These innovators and early adopters stimulate the development and spread of new technologies by which they can accelerate the transition (Rogers, 1996). The faster a sector makes a transition the more emissions are reduced, the Rijksrederij could thus create benefits for the environment by accelerating the transition.

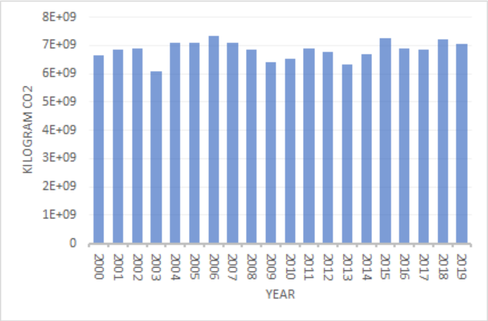


**Figure 1.1:** Shipping emissions on Dutch waters from 2000 till 2019, data from (CBS, 2020)

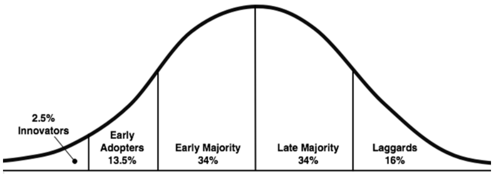


**Figure 1.2:** Diffusion of innovation (Rogers, 1996)

## 1.2 Rijksrederij

The Rijksrederij manages, mans and maintains ships for Customs, the Coast Guard, the Ministry of Agriculture, Nature and Food Quality and Rijkswaterstaat. This requires a diverse fleet of both inland and seagoing vessels, a few of these can be seen in figure 1.3. They have a total of 109 vessels and an annual turnover of approximately €100 million euro. The vessels are located in all the possible operational areas in the Netherlands, which can be seen in figure 1.4. In 2019 the fleet of the Rijksrederij produced 35.6 million tons of CO2, which is approximately 0.5% of the shipping emissions on Dutch waters.
The Rijksrederij is planning to run their climate neutral fleet on batteries, hydrogen and methanol. Which of these three will be used for a specific vessel depends on the energy requirements. Vessels with a low energy requirement will run on batteries, hydrogen will be used when it is not possible to store enough energy in batteries and methanol will be used if hydrogen is also not sufficient. The Rijksrederij is currently planning pilot projects for each of these energy carriers as a first step in the transition. These projects can be used to develop knowledge, experience and trust with the new way of operating, the results can be valuable for the entire sector. They can be the seeds for the needed systemic change and are therefore crucial for the transition (Geels, 2012).
Climate neutral options are in general not able to out-compete the established ways of doing on price or performance, especially when they are not yet fully developed (Geels et al., 2017). This is thereby also a barrier for further development, since commercial organizations might not be able to win back any investments in climate neutral sailing. The Rijksrederij strictly works for other governmental organizations, has no commercial aim and no competition. They do have an ambitious transition plan which can be funded by the government without undermining the level playing field in the sector. This makes the transition of the Rijksrederij an interesting case. They have a unique position in the sector which could prove them to be of enormous value for the energy transition, by making developments other parties cannot afford.

**Figure 1.3:** Some of the vessels of the Rijksrederij, illustrating their diverse fleet

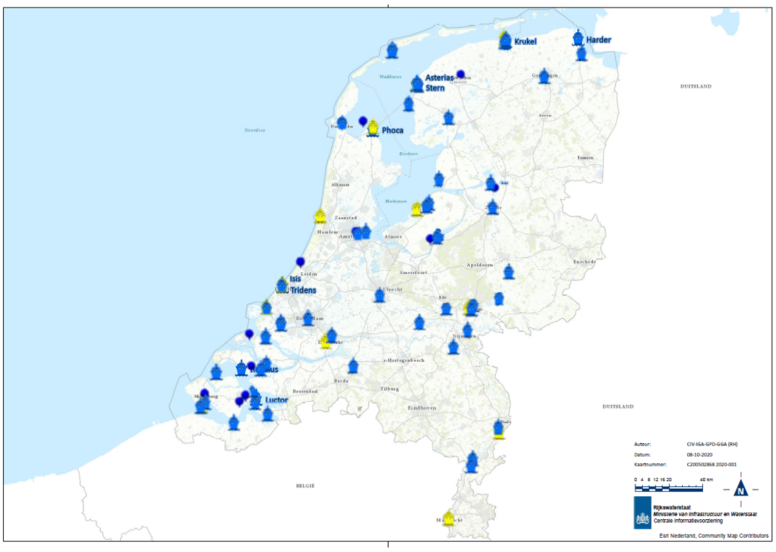


**Figure 1.4:** A map of the Netherlands with the locations of Rijksrederij vessels in blue and yellow

## 1.3 Problem definition

A transition to climate neutral energy carriers while maintaining operational and competitive capacities will be vital for the Dutch economy and the global environment, but also a complex process. Launching customers of climate neutral sailing are considered to be crucial for transitions and should be able to have a stimulating effect, by enabling others to make a transition based on their developments. A higher transition pace will benefit the environment since it will lower the contributions to climate change. Furthermore, it will give the Dutch shipping sector a chance to become a leader in climate neutral sailing which can increase the competitive capacity. The amount of launching customers in the current Dutch shipping sector is however limited, which means that the transition has barely started and the emissions remain high. In-depth knowledge on the current transition barriers, required enablers and value of pilot projects which could substantiate a strategy for the Rijksrederij and gain the necessary support is currently missing. Without this knowledge launching customership by the Rijksrederij might very well not happen, which would be a loss for both the environment and the economic competitiveness of the Dutch shipping sector.

## 1.4 Objective

The overall objective is to determine the potential added value of launching customership in the energy transition of shipping in the form of transition enablers. The focus will first lay on the transition barriers which will lead to the required transition enablers, then the focus will converge to the transition enablers that can be created by launching customers. The objective is to study both launching customers in the Dutch shipping energy transition in general and specifically the case of the Rijksrederij and its pilot projects. These research objectives have led to the following research question and sub-questions.

**Research question**

**What are the transition enablers that can be created by launching customers in the energy transition of the Dutch shipping sector?**

**Sub-questions**

The scope for the questions will be the Dutch shipping sector in general but also focus specifically on the fleet of the Rijksrederij.

- What are the transition barriers that obstruct or slow down the energy transition of the Dutch shipping sector?
- What transition enabling developments are required to create a pathway to a climate neutral Dutch shipping sector?
- What are the transition enablers that can be created by launching customers and specifically their pilot projects?

**Definitions:**

**Launching customers**

Innovators and early adopters which are the first 15% of adopters, as defined by (Rogers, 1996) and illustrated in figure 1.2. This thesis will focus on the Rijksrederij. They will be launching customer of many vessels when they carry out their transition plan.

**Energy transition**

The transition from the use of carbon-based energy carriers to climate neutral energy carriers. Climate neutral: as defined by (Verheijen, 2020) of the Rijksrederij; no net CO2 emissions over a short time span; no compensating measures and no emissions of other Green House Gasses (GHG) or harmful substances like PM (particulate matter), NP, NOx en SOx.

**Environmental benefits**

These are subdivided in direct and indirect environmental benefits. The direct environmental benefits are seen as reductions in greenhouse gas emissions at the Rijksrederij and its direct operational partners. The indirect environmental benefits relate to other actors in the shipping sector, enabling them to innovate or operate towards a more environmentally friendly shipping sector and thereby reducing the costs of an energy transition for other ship owners.

## 1.5 Research structure and scope

This research project is subdivided into five phases: literature study, solution design, explorative interviews case studies and finally a reflection phase. The scope refines as the research progresses, in the final phase the scope broadens again. This can be seen in figure 1.5.

The literature study gathers relevant knowledge regarding the research topics and prevents that research is conducted that has already been done. The results led to a theoretical transition framework which was filled with shipping specific literature, this can be found in chapter 2. A detailed description of the literature study objective and approach can be found at the beginning of this chapter.

The second phase is the solution design, which can be found in chapter 3. The plan of approach for the rest of the thesis was developed, based on the theoretical framework and research methods. This chapter starts with an adjusted transition framework that leads to the answer of the research questions which is followed by the methods for the following phases.

The following two phases are research by semi-structured interviews and case studies, of which the results can be found in chapter 4 and 5. The interviews provided the qualitative knowledge and insights that were required to answer the research questions. Case studies provided depth, detail and context to the obtained knowledge and insights that further substantiate the answers of the research questions.

The final phase of the thesis consists of a reflection on the research that leads to the discussion, conclusions and recommendations. These can be found in chapters 6, 7 and 8. These are followed by the appendixes and a list of references.

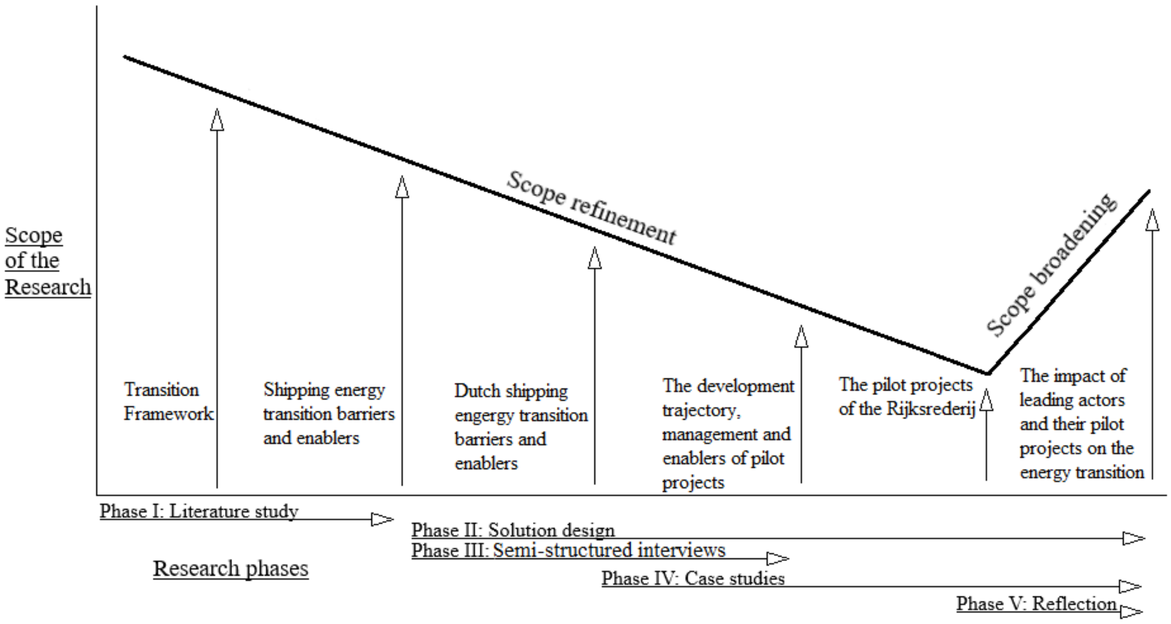


**Figure 1.5:** Scope of the research during the different research phases

# Chapter 2

# Theoretical Framework

The objective of the literature study is to find a theoretical transition framework and fill this with shipping specific literature. The framework will give structure to the transition process and the obtained literature, which is crucial for this multidimensional subject. It will give an overview of the state of the art of transition theory and its application to the shipping energy transition. Possible gaps in the theory or the application will be a good starting point for conducting further research. The literature study will also be used to collect methods that can possibly be used in later phases of this thesis.

## 2.1 Introduction

This introduction will discuss the scope, literature collection approach, selection of transition theory and structure of the theoretical framework.

### Scope

The transition framework should not only focus on the technical, economical or sociological side of the transition but use a socio-technical approach, to ensure that a relevant overview is obtained. This takes into account the various elements of the existing shipping sector, these elements are e.g. technology, policy, markets, consumer practices, infrastructure, cultural meaning and scientific knowledge (Kemp et al., 1998). All these elements influence the transition pathway by their individual or mutual structures and dynamics. This approach highlights the multi-dimensional interactions and co-development in the sector, which creates transition barriers. The framework should also include an option for a transition of the existing shipping sector and help to understand how this is established. The search for shipping specific literature will focus on the transition barriers, climate neutral sailing practices, drivers for the transition and other factors that are included into the transition framework.

Theories that are relevant for pilot projects will also be collected, since the focus of the research will converge towards pilot projects. These can be seen as an addition to the transition framework and are structured as theory on developing climate neutral sailing practices. It will be the first step in answering the third sub-question on the environmental benefits that can be created by pilot projects. This literature study would ideally focus on the energy transition for typical Rijksrederij vessels that operate in the Netherlands. However, literature and transition theory on such a specific topic will be scarce if not nonexistent. Therefore, the scope will be wider, focusing on the energy transition at a sector wide scale and the place that niches and thus pilot projects have in transition theory. The study will focus on literature for Rijksrederij specific vessels, operations and operational areas when this is obtained. Articles that focus on an energy transition in other sectors such as automobile or aerospace will be excluded from this study, since this would make the scope too wide.

### Literature collection approach

The literature study starts with systematically collecting papers and reports, which requires a search strategy and database. The “snowball method” is selected, where one starts with one or a few relevant papers and uses the references and keywords to obtain more literature. One can obtain a lot of relevant literature in a short time span with this method, which is valuable given the time limit for this research phase. The obtained literature will be scanned for any information that can contribute to the literature study objective based on the titles and the abstracts. The findings can be used to refine the search terms. The Ph.D. research plan of Jurrit Bergsma was selected as a starting point for the snowball method (Bergsma, 2019). When all relevant literature is collected it is time to read and analyse it in more detail, starting with the most cited and recent papers. The goal is to get an overview of the following:

- the most influential researchers
- the usual research approaches
- the current state of the art
- the relevance of the research topic
- gaps in literature

**Transition framework**

There are four significant options for frameworks that are used in literature: the Diamond model (Porter, 1990), the Sectoral Innovation System theory (Wieczorek et al., 2013), the Technology Based Sectoral Change framework (Dolata, 2009) and the Multi-Level Perspective on socio-technical transitions (Geels, 2002). The first two frameworks are not considered because they do not focus on sectoral transitions and are therefore not applicable. Dolata's framework is based on two factors, the transformative capacity of new technologies themselves and the sectoral adaptability of socio-economic structures. The multi level perspective focuses on transition pathways and how the multiple levels must align before a transition is possible.

In the (Geels, 2012) the multi-level perspective is introduced into transport studies to assess the drivers, barriers and possible pathways for low-carbon transitions. It has since been used many times to assess transitions for transport sectors, even for the shipping sector (Pettit et al., 2018) and for the niches slow steaming and wind propulsion (Mander, 2017). This is in contrast with Dolata's framework appears to be used significantly less, no examples were found in which it was applied to the shipping sector. The multi-level perspective is well developed with articles about transition pathways (Geels and Schot, 2007), niche development which includes an analysis of the impact of pilot projects (Geels and Raven, 2006) and responses to criticism (Geels, 2011). It is therefore considered to be the best candidate for a theoretical transition framework.

**Structure**

The multi-level perspective will be explained in more detail in the next section, including theories on niche development. This is followed by three sections in which shipping specific literature is placed in the three levels of the MLP framework. First an overview of the characteristics and stabilizing lock-in mechanisms of the current fossil fuel based socio-technical system in section 2.3. Second the shipping Landscape in section 2.4 and third the shipping niches in section 2.5. The analysis of these three levels will paint a picture of what the shipping transition path will look like and what the relevant elements are, this is discussed in section 2.6. Next is an analysis the role pilot projects and transition of the Rijksrederij in section 2.7. And finally overview of the found methods in section 2.8, a summary of the literature study in section 2.9 and recommendations for further research in section 2.10.

## 2.2 The multi-level perspective on transitions

The Multi-Level Perspective (MLP) is an analytical framework for transitions that tries to create a holistic view that includes economical, engineering, sociological, political and ecological point of vies (Geels, 2012). It conceptualizes overall dynamic patterns at multiple levels and analyses the interaction between these levels. These are the niche, regime and the landscape level. The framework originates from (Kemp et al., 1998) and (Geels, 2002). The MLP includes and combines evolutionary economics, science, technology studies, structuration theory and neo-institutional theory.

The regime level is based on the notion of a socio-technical system, which consists of multiple elements that are aligned with each other. This alignment is what makes the regime work efficiently, therefore it is protected and constantly reproduced by the regime actors which creates stability. In the shipping sector the technology, infrastructure, regulations, market and user practices and mindset are all aligned with fossil fuel based technology which creates specific 'ways of doing'. This alignment creates a "lock-in" on the technology and only allows for incremental change to the elements. The socio-technical regime interacts with the even more stable exogenous socio-technical landscape and the unstable niche level where radial innovations can occur since there are no strict 'ways of doing'. A transition arises when developments in the landscape put pressure on the existing regime and a niche is better aligned with the new landscape, the niche can then compete with the regime and replace it. In figure 2.1 the multilevel perspective on transitions is visualized.
The MLP has been introduced as an analysis for low-carbon transitions in the transport sector (Geels, 2012) and theory on niche development has also been further developed (Geels and Schot, 2007; Geels and Raven, 2006; Jensen et al., 2007; Geels et al., 2017), these studies will now be used to explore the levels in more detail. The niche level is particularly interesting since that is where the Rijksrederij will be operating with pilot projects. The regime will be discussed first, since this is the central level which represents the larger part of the sector. Then the landscape level will be discussed since this is the exogenous context to both the regime and niche and the 'highest' level in the MLP. The niche will be discussed last since its the 'lowest' level and is best understood when the other levels have already been introduced.

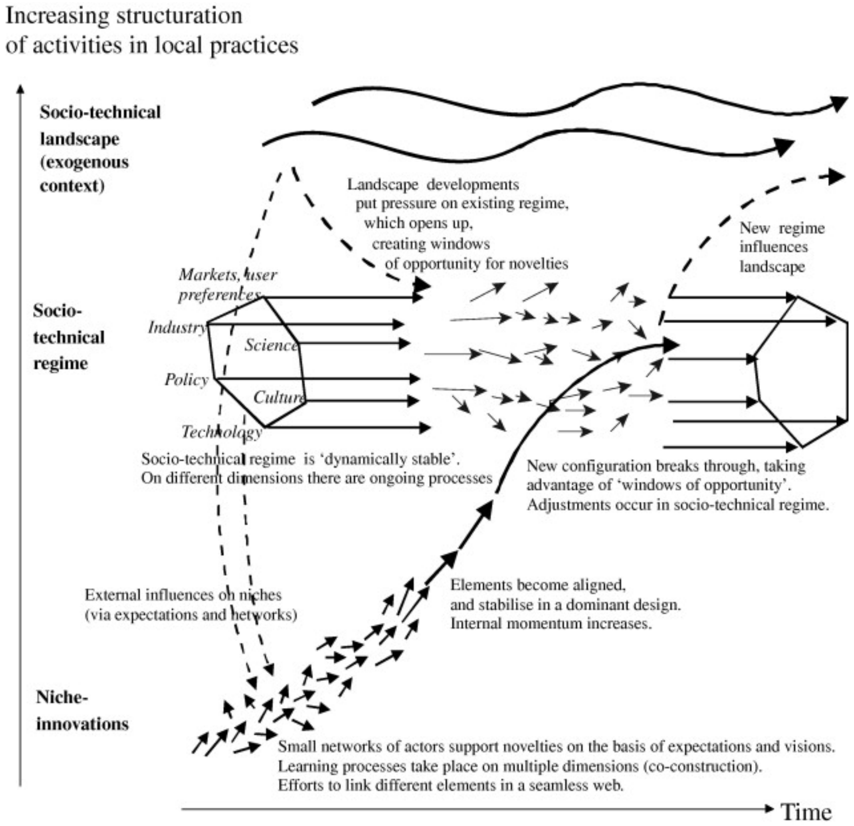


**Figure 2.1:** Multi-level perspective on transitions (Geels, 2012)

### The socio-technical regime

Socio-technical systems consist of multiple elements that are well aligned with each other and thereby create stability, lock-in of e.g. technologies and perceptions and path dependency in innovation. The elements are usually identified as technologies, infrastructure, regulations, market and user patterns, and mindset. The actors in the system follow deep-structural rules on which they base their perceptions and actions, they follow 'the rules of the game' which lead to deeply embedded 'ways of doing'. By following these rules, they largely maintain the existing regime and only make incremental changes. The 'rules of the game' are thereby both the origin and outcome of actions, the "duality of structure" (Geels, 2011). The innovations and changes within a regime are thus mostly incremental because of lock-in mechanisms and path dependency which act as transition barriers. The changes to the regime do not cause instability because they follow relatively predictable trajectories, the established direction of innovation that the regime was expecting. This does not only occur in changes of technology but also in the other elements of the regime, although each element might have its own dynamics, they are interdependent and co-evolve together. The lock-in mechanism and path dependence arise from e.g. cognitive routines, shared beliefs that make actors blind for developments outside their scope, shared capabilities and competences by shared education, deeply embedded user practices, institutional arrangements, regulations or market entry costs that create market entry barriers, legally binding contracts, sunk investments in technology, infrastructure or people, resistance from vested interest and low costs due to economies of scale (Geels, 2012) (Geels, 2011).

By taking the view of a regime with multiple elements the MLP goes beyond most of the other transition and innovation theories that focus on a certain technology to play a pivotal role in the transition. Some actors have a large influence with their product offerings, marketing strategies and political lobbying but are not the only actor that maintains the regime. The culture, infrastructure, rules and regulations, markets and user practices and knowledge are also key elements in preserving a certain technology in a regime. (Geels, 2012). Even when engineers would develop capable technologies there is still a large inertia in the other elements that needs to be dealt with before a regime makes a transition to the new technology, as a result of the multitude of lock-in mechanisms that can occur at the different elements.

A socio-technical regime is a combination of the theory of a regime and a socio-technical system. A regime is an analytical concept focusing on the deep structure, intangible rules such as shared beliefs, norms and standardized ways. It assumes that the behavior of actors is constrained by this structure and that this cannot be easily changed. The idea of socio-technical 'systems' focuses more on measurable elements, tangible elements such as technology, market size, infrastructures and regulations (Geels, 2012). The socio-technical regime combines the two which enables an analysis of both tangible and intangible elements and the lock-in mechanisms that they create.

### The socio-technical landscape

The socio-technical landscape is the exogenous background, the wider context that influences niche and regime dynamics. Examples of landscape elements are spatial structures, macro-economic trends, political ideologies, societal values, beliefs, concerns and the media landscape. It is thus not only a symbolic term but also a literal one since spatial structures like canals and bridges that influence vessel size are considered part of the landscape. It is something we are all a part of and cannot easily be influenced by individual actors in the short run, it is sustaining. The landscape therefore has the greatest degree of structuring and usually changes slowly (Geels, 2011) (Geels, 2012). When one travels through a landscape some directions are easier to travel in than others, socio-technical landscapes provide these 'gradients of force' that make some actions easier than others (Geels and Schot, 2007). This can push the regime to move in a certain direction, a change in the landscape can put a lot of pressure on the regime.

Landscape pressures can be multidimensional, e.g. climate change concerns in combination with a growth in global trade and a low oil price. Landscape-pressures such as increasing concerns about climate change have increased slowly leading to the Paris agreement which puts pressure on many sectors (United Nations, 2015). There are also landscape pressures that suddenly arise creating a disruption, such as the 911 terror attacks on the aviation sector (Geels and Schot, 2007) or large oil spill accidents in the shipping sector. The type of landscape pressure determines in part the transition pathway.

### Niches

Niches are conceptualized as 'protected spaces' with conditions that differ from the socio-technical regime, the lock-in dynamics are not or only partly present. These spaces can be research and development laboratories, subsidized projects, small market niches or pilot projects. Within these niches there is opportunity or even a stimulus to develop of radically different ways of doing with their own socio-technical elements. In normal regime conditions these would not survive, since they are not aligned with

the established technology, infrastructure, regulations, market and user practices and mindset. Niches are crucial for regime transitions, because they provide the seeds for systemic change (Geels, 2012).
The goal of these niche actors is to make the existing regime adopt their innovation or even replacing the regime by one that includes their innovation. To stand a change the novelty needs to develop within the niche by working together with all relevant actors. Three social processes are distinguished within niches: learning processes, the articulation and adjustments of expectations or visions and the building of social networks (Kemp et al., 1998). The learning processes get rid of imperfections and issues with for example technology, user practices or other socio-technical elements. A safe niche environment is required, for example a non-commercial pilot project. The process of articulation and adjustments of expectations or visions converges the direction for internal innovation activities, this makes the niche evolve towards a stable system and design. Niche projects can also attract attentions from external actors, which creates an opportunity to start building social networks and expanding the resource base of niche innovations, which can lead to a stable community (Geels and Schot, 2007).
When analyzing a niche and the potential for a transition the state of development of the niche-innovation is an important aspect for the path of the transition. To assess if a niche-innovation is 'fully developed' (Geels and Schot, 2007) suggests four objective criteria based on earlier work of (Kemp et al., 1998) and (Rogers, 1996). These criteria are "(a) learning processes have stabilized in a dominant design, (b) powerful actors have joined the support network, (c) price/performance improvements have improved and there are strong expectations of further improvement (e.g. learning curves) and (d) the innovation is used in market niches, which cumulatively amount to more than 5% market share" (Geels and Schot, 2007).

Niches and socio-technical regimes are similar kinds of structures, communities of interacting groups, but they differ is size and stability. Socio-technical regimes have large and stable communities that share certain well articulated and established rules, the 'rules of the game'. Niches are unstable and the rules are still in the making, they are still being figured out and the community members are not fully aligned. The rules that structure the behavior of the communities can be subdivided into three kinds: regulative (regulations, standards, laws), normative (role relationships, values, behavioral norms) and cognitive (belief systems, innovation agendas, problem definitions, guiding principles) (Geels and Schot, 2007).

### Transition pathways

A transition is defined as a change from one socio-technical system to another, this is a result from interactions between the three levels. "The multi-level perspective argues that transitions come about through interactions between processes at these three levels: (a) niche-innovations build up internal momentum, through learning processes, price/performance improvements, and support from powerful groups, (b) changes at the landscape level create pressure on the regime and (c) destabilization of the regime creates windows of opportunity for niche innovations"(Geels and Schot, 2007). When these three processes line up, this is to say they occur simultaneously, the niche can replace established regime or parts of it.
In (Geels and Schot, 2007) the typology of five kinds of transition pathways are identified and discussed. These are the transformation path, the de-alignment and re-alignment path, the technological substitution path, the reconfiguration path and the sequence of transitions path. Which pathway applies depend on the magnitude and form of landscape pressures, the state of development of the niche technology and the adaptability of the niche. The technological substitution and transformation path are considered to be interesting for this thesis since they relate to previous and current shipping energy transitions.
The Transformations path applies when "there is moderate landscape pressure at a moment when niche-innovations have not yet been sufficiently developed, then regime actors will respond by modifying the direction of development paths and innovation activities" (Geels and Schot, 2007). Outsiders are important in this pathway since they draw attention to negative externalizes that regime insiders tend to neglect or do not see, which creates pressure for change. This strengthens the niche innovation which cannot compete with the existing regime on price and performance. It is a 'goal oriented' transition path by which the goal is societally incentivized and thus originating from outside the regime. Regime actors reorient their development trajectories to find technical variations that have a better fit with the slowly changed landscape. Hereby they rely on their adaptive capacity and niches to bring them innovations. When the 'distance' between the existing knowledge and new knowledge is to large they will have to import external knowledge. The new regime slowly grows out of the old regime by cumulative adjustments

and re-orientations, regime actors usually survive. It is thus a pathway of gradual adjustments of regime rules as a result of landscape developments and struggles between regime actors and relative outsiders that do not agree with some of the regime characteristics.
The Technological substitution path applies when "there is much landscape pressure ('specific shock', 'avalanche change', 'disruptive change') at a moment when niche innovations have developed sufficiently, the latter will break through and replace the existing regime". This transition is 'emergent', it arises when commercially incentivized actors find new technologies with better price or performance than existing technology. The transition from a sailing ship regime to a steamships regime in Britain is provided as an example, this transition is illustrated by a graph in figure 2.2. The British government created a subsidized market niche for mail steamships, which were faster and had reliable arrival times but were also more expensive than sailing clippers. This niche provided a space where the steamship technology and community could further develop and radical innovations were possible. This led to screw propeller replacing paddle wheels, coal efficiency improvements by building larger engines and a shift to iron hulls which could support these engines and be build larger to carry more cargo. When the Suez Canal opened in 1869 steamships could pass through it while sailing ships had to travel around Africa. This change in the spatial landscape together with the developments of the steamship niche led to the transition from a sailing ship regime to a steamship regime through economic competition, the steamships had a better fit with the changed landscape. The incumbent sailing ship manufacturers focused on improving their sailing ships and could not make the switch to iron and steam, which made them go out of business.

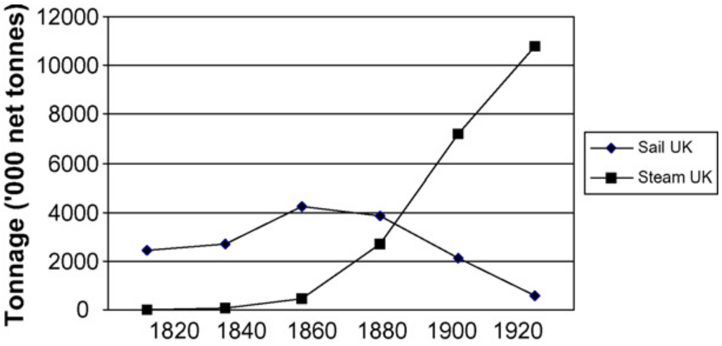


**Figure 2.2:** Tonnage of steamships and sailing ships in Britain (Geels and Schot, 2007)

### Non-linearity and the governance of transitions

The transition from sailing ships to steamships was a linear transition as can be seen in 2.2, this is however not always the case with transition pathways. Non-linearity is defined as a change in the direction of niche development trajectories. This is subject to a change in the content of cognitive rules and expectations, which in turn drives research and development. As long as the cognitive rules and expectations are positive towards a new technology there is a stable trajectory. This can be created by e.g. positive outcomes of learning processes, expectations that link technology to functional applications and the support from social networks. However, when learning processes produce results that do not match the expectations is can cause a backlash. When the belief of actors in the innovation falls apart networks will fall apart too, resources will shrink and the developments in the technology will decline (Geels and Raven, 2006).
Low-carbon transitions involve not only firms and consumers but also a wider range of actors such as the media, political parties, advisory bodies, government ministries, etcetera. The cognitive rules and expectations that have a big impact on niche development trajectories are influenced by the beliefs, conflicting values, competing interests, unequal resources and complex social relations between all actors involved in low-carbon transitions. Low-carbon transitions can therefore be particularly non-linear, as is illustrated in figure 2.3. This figure shows a hype-disappointment cycle for green car propulsion technologies.
When guiding radical transitions towards low-carbon regimes one has to deal with uncertainties about future price and performance, social acceptance, consumer interest and policies. There will also be disagreements about which solution is the most desirable, which policy should be applied and what the

costs and benefits will be. The policy makers that have to deal with this are not all-powerful actors but are dependent on other actors themselves (Newig et al., 2007). In the case of low-carbon transitions the price and performance of sustainable solutions might never out compete the established technologies without changes in regulations such as a carbon tax or subsidies (Geels, 2011). These regulatory changes require powerful authorities, if they are not present a deadlock can arise in which fully developed climate neutral solutions cannot out compete the established fossil fuel based ways of doing. This can also cause a hype to turn into a disappointment.

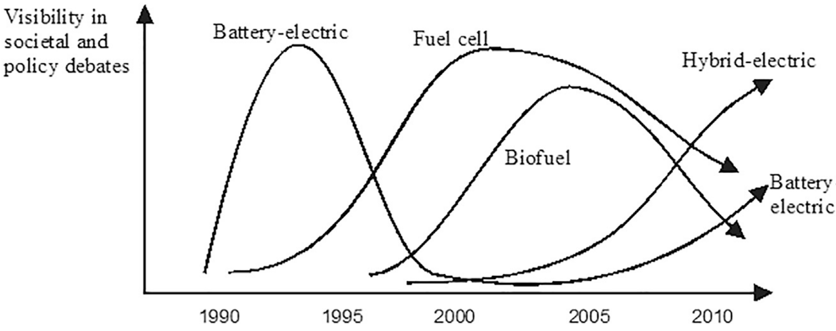


**Figure 2.3:** Hype-Disappointment Cycles for Green Car Propulsion Technologies (Geels, 2012)

### Strategic niche management and doing, using and interacting

For a niche to gain momentum its visions must become increasingly accepted, the learning process must converge to a dominant design and the social networks should expand. This will help to build the legitimacy of the niche, especially when powerful actors join in with lots of resources and established credibility. The spreading of new visions and ways of doing will put pressure on the regime. This can be achieved by experimental, pilot or demonstration projects, which create practice-based learning and marketing modes. These projects are thus important for the development of niches and a key link in making a regime transition (Geels and Schot, 2007).

The trajectory of a niche depends on the cognitive rules and expectations, which in turn depend on the learning processes within the niche, as was discussed before. Strategic Niche Management (SNM) literature helps to understand the dynamics behind niche management and conceptualizes pilot projects with new technologies as an important phase between research and development and market diffusion. Pilot projects, just like demonstration or experimental projects, provide three things: space for interactions between actors and the building of social networks, space for learning and the articulation of expectations and visions. This leads to knowledge development and aligns the technical design, user preferences, regulations, infrastructure requirements and cultural meaning. These projects also attract attention, which is important for obtaining resources (Geels and Raven, 2006).

The goal of these projects is to obtain generic lessons and cognitive rules. This includes standardization, codification, model building, formulation of best practices etcetera. This can be achieved by doing multiple projects at the same time and combining the experiences of these local projects into a more global overarching network. This will articulate the initially diffuse broad and unstable rules and expectations and make the niche more stable. This circulation of knowledge can be achieved by building a community that organizes workshops, conferences, writes newsletters etcetera. When the network has a shared belief in the new technology it will also be easier to attract investors (Geels and Raven, 2006). This process is illustrated in figure 2.4 and figure 2.5.

To further understand the learning processes that lead to innovative technologies the theory from (Jensen et al., 2007) will be introduced here. It makes a distinction between the Science, Technology and Innovation (STI) mode and the Doing, Using Interacting (DUI) mode. The first tries to get a general scientific understanding of what artefacts and techniques work for a certain problem and why. This mostly takes place in research and development laboratories and scientific institutions. However, “much of practice in most fields remains only partially understood, and much of engineering design practice involves solutions to problems that professional engineers have learned ‘work’ without any particularly sophisticated understanding of why” (Nelson, 2004). This knowledge can be developed by DUI. Operators of new innovative technologies acquire their knowledge for the most part on the job, they need to know

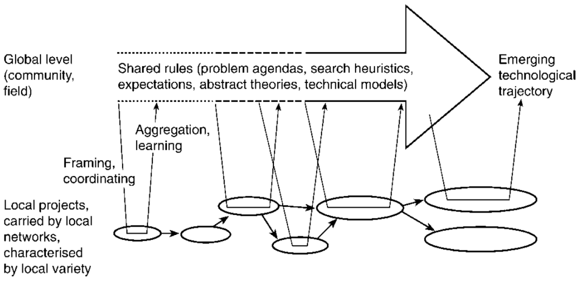


**Figure 2.4:** Technical trajectory carried by local projects (Geels and Raven, 2006)

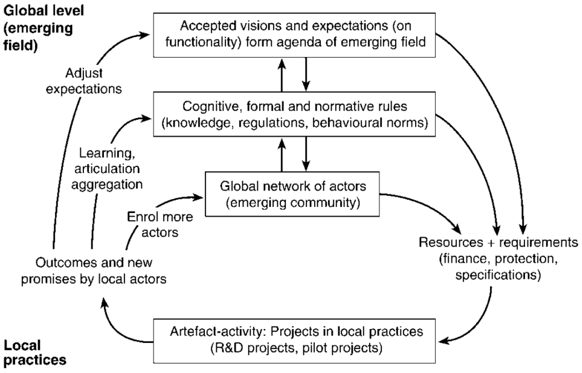


**Figure 2.5:** The dynamics of niche development trajectories (Geels and Raven, 2006)

how, not know why. DUI also develops links and communication between designer and operator, which is crucial for innovation. (Jensen et al., 2007) performed an empirical study on which modes of innovation where used by Danish firms and their innovations performance. The study showed that a combination of the STI and DUI really improved innovation performance. Based on the definition of DUI a pilot project can be seen as DUI learning process.

## 2.3 The current carbon-based socio-technical shipping regime

The socio-technical shipping regime has multiple actors: shipbuilders, shipowners, ports, regulators e.g. the IMO, branch organizations, financial institutions, service providers, energy suppliers, etcetera. In figure 2.6 the three levels are presented according to (Pettit et al., 2018). All these elements are to some extend aligned with each other which allows them to work together. The Dutch shipping regime is however a bit more complex, therefore it seems logical to make some further distinctions. These distinctions between different groups within the regime create sub-regimes, e.g. a yachting, container carriers, inland work vessels or a crude carrier sub-regime. Within these sub-regimes alignment is stronger and specific regime rules are dominating. Distinctions in the location of the regime can also be made, e.g. the Dutch inland working vessel regime might differ quite significantly from the one in the United states. Some subsets are so small that there is no stable community with strong alignment and specific 'rules of the game', in that case it is not categorized as a sub-regime but as a niche. An example of this can be nuclear submarines or electric tugs. In the bigger picture the sub-regimes will still have a lot of similarities in terms of prevailing technologies, overarching regulations, infrastructure and probably also culture and mindset which can lead to overarching lock-in mechanisms. Literature concerning these regime characteristics and lock-in mechanisms will now be discussed.

### Pressure from regime regulations

Regime regulations put pressure on the regime to make incremental changes to the established 'rules of the game'. A distinction can be made here between hard policies that enforce measures and soft policies that stimulate certain measures. Multiple hard policies for the reduction of harmful emissions have already been imposed by the IMO and the EU. For example, the Energy Efficiency Design Index that requires new ships to be respectively 10%, 20% and 30% more efficient than a baseline of similar sized vessel in 2015, 2020, and 2025. There is also legislation for all currently operating vessels, the Ship Energy Efficiency Management Plans, these are both set by the IMO (Pettit et al., 2018). There is also the introduction of sulphur control areas (Mander, 2017), the 2050 IMO Greenhouse Gas reduction goal (IMO, 2018). However, these changes in regulations only lead to incremental steps in efficiency over the coming decades, which might not even be enough to counteract the grow of emissions caused by a grow in world trade.

(Pettit et al., 2018) found that although efficiency is increasing so is fuel consumption, due to the growth in world trade. However, regulations do encourage or even enforce the adoption of technologies that generate less emissions, beyond the forces of the market. A literature review (Makkonen and Repka,

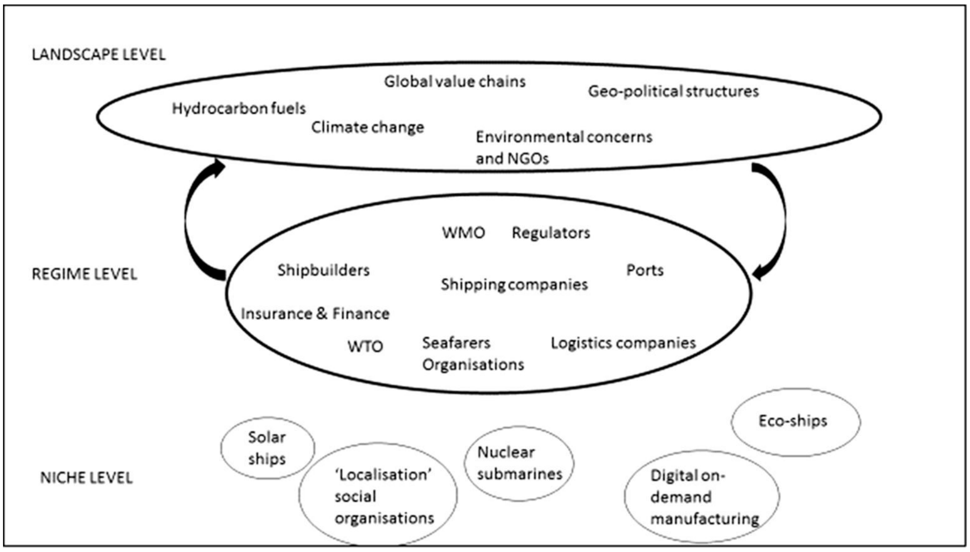


**Figure 2.6:** Multi-level perspective of socio-technical transitions applied to shipping, according to (Pettit et al., 2018)

2016) on the innovation inducement impact of environmental regulations found no clear proof for this impact. An overview of the literature on the impact on economic competitiveness was also inconclusive, the only clear positive effect of the regulations was improved health and environmental benefits.

Soft policies can be found at several ports that have started to use GHG emission ratings to attract more efficient vessels (Pettit et al., 2018) and at leading banks in shipping that take the efficiency of vessels into account before making investments (Poseidon Principles, 2020). Another example are subsidies for projects contributing to the energy transition, which are offered by organizations such as the EU in the Green Deal (ECSA, 2020).

Addressing the current environmental problems requires a factor 10 or higher improvement of environmental performance (Geels, 2011). This will clearly not be achieved with the current regulations. Given the regulatory system of the shipping regime it is not to be expected that regulations leading to a factor 10 or higher improvement of environmental performance will be adopted any time soon.

### Lock-in mechanisms resulting from shipping technology, shipbuilding and infrastructure

A new ship is a large capital investment, especially if it is a launching customer of new innovative technology. The owner of a new ship therefore faces high risks concerning the return on his investment, since the technology often has not been validated in real life prototypes since this would be expensive. In comparison with launching customers in many other sectors, where investments often are smaller e.g. when buying a car, the amount of capital that is at stake is significantly larger. When the new technology of a vessel also requires its own infrastructure, e.g. for bunkering a climate neutral energy carrier, the investment is even larger. One can imagine that if there is no large financial benefit from the new technology a commercial cost-benefit analysis would favor the existing technologies over the new ones. Regimes that rely on technologies that require large capital investments and associated infrastructures can be hypothesized as 'strongly embedded', which leads to high path dependency (Geels, 2002).

Many vessels that are build are at least partly custom designed and can therefore be seen as prototypes, this requires new concepts to be implemented right the first try which increases risk adversity in the sector (Wijnolst and Wergeland, 2009). It makes shipowners hesitant to invest in a new technology that has not been proven by clear independent data on its performance and makes shipyards reluctant to implement innovative technologies in their new build vessels (Gilbert et al., 2014; Faber et al., 2011). The small number of similar vessels that are being built also limits the scalability of innovations, which limits the possible costs of innovation. This could be further decreased by limited knowledge sharing between sub-regimes and operational areas. There are thus lock-in dynamics in existing technology because of the high costs of market entry and innovation, sunk investments, high risks and low scalability.

### Lock-in Mechanisms resulting from market and user practices and mindset

Businesses in the shipping regime have in general strong objectives for commercial gain, which makes a positive cost-benefit analysis for innovative projects important. Radically innovative projects are seen as a high risk due to their uncertainty which gives them an unfavorable cost-benefit result (Psarros and Mestl, 2015). The companies experience fierce global competition in their quest for profit (Psarros and Mestl, 2015) and their success is highly influenced by economic trends, in an economic downturn a lot of knowledge and innovation can be lost (Europen Commission, 2015). Since the regime has a strong status quo in standards the vessels of competitors are quite similar creating a level playing field between actors (Wijnolst and Wergeland, 2009).

Shipowner do not always pay for their fuel costs themselves which reduces the incentive for shipowners to become more efficient (Mander, 2017). This is the result of charter contracts in which the customer pays for the fuel. Many companies do not measure or manage their fuel consumption since this was not a priority for shipowners (Mander, 2017). These lock-in mechanisms are caused by cognitive rules, shared beliefs, deeply embedded user practices, institutional arrangements and the way contracts are set up.

There is a large number of diverse actors operating in the shipping regime such as shipyards, shipping companies, ports and other commercial organizations. Most of these actors are small and not well aligned with actors outside their sub-regime, there are 150 shipyards entities in the European Union alone (Europen Commission, 2015). These actors are often seen as conservative, feeling resistance for radical change (Mander, 2017). Which would indicate that they rather stick with the existing regime than adopt innovative niches. Their traditional mindset is inward focused, with a limited interest to show leadership for issues outside the shipping domain (Jenssen and Randøy, 2006). This would mean that regime actors also have limited interest in being a leader in an energy transition to prevent climate change, some might not even want to partake in such a transition. (Dewan et al., 2018) found that barriers for adoption of energy efficiency operational measures in shipping industry are the lack of information, awareness and crew competence. Operational difficulties, financial issues and the interests of the ship owners are also barriers. It seems that the mindset of the actors is the root of most of these lock-in mechanisms. This is another aspect of the shipping sector that stabilizes the existing regime, by cognitive routines and beliefs that favor the existing regime over niche-innovations or make actors blind for what niche innovations outside of their scope could bring them.

## 2.4 Socio-technical landscape

The socio-technical shipping landscape consist of external elements such as oil price or hydrogen price, world trade developments, politics, sailing infrastructures such as the Suez Canal or more locally certain narrow bridges, environmental concerns, NGO's such as Greenpeace, external technological developments such as digitization, etcetera. Developments and changes in these elements have put pressure on the existing socio-technical regime and steered it in the past. It is therefore interesting to look at these dynamics and see what pressures might arise in the future. Note that landscape development can have different effects on sub-regimes, while world trade is extremely important for container carriers it might only have a limited impact on the yachting sub-regime.

### Pressures from world trade

For international shipping the world trade developments are extremely important. Shipping is an enabler of international trade, about 90% of goods are transported by ships (Nikolakaki, 2013). Between 1990 and 2014 the transport capacity of the shipping sector doubled, the annual average growth was 4% (Pettit et al., 2018). Developments in global trade have shaped the shipping sector, some macro-economic trends stabilize the existing regime while others destabilize it creating opportunities for regime change (Mander, 2017). Global trade is likely to grow in the future, which will have a stabilizing effect on the existing regime. (Pettit et al., 2018) argues that trade liberalization which led to a differentiation in production and consumption locations is the big driver behind the major commodity flows that stimulating by the shipping regime. This makes the economy as a whole dependent on the shipping regime, leading to powerful vested interests into the regime which is a significant barrier for change. The expected growth of the shipping economy makes it even more important that an energy transition will take place since GHG emissions will have grown 150-250% by 2050 in a business as usual scenario (Bouman et al., 2017).

Incremental improvements in the technology will be inadequate to compensate for this (Mander, 2017). Since the transition will probably become increasingly difficult as the sector becomes larger, because of even higher sunk investments, it is also wise to start the transition as soon as possible. This would certainly also be favorable climate wise. In figure 2.7 different emissions scenarios are plotted to illustrate the wide range of future scenarios.

Structural shifts in production systems, making them more spatially-bounded and circular, would reduce emissions significantly by taking away the big driver behind the merchant fleet. Although this idea is supported by certain social groups it is not expected that it will have a big influence on the world economy (Pettit et al., 2018). But it is possible that a new view on the social responsibly of some companies makes them reconsider the length of their supply chain and the way in which they transport their goods (Mander, 2017). There are expectations that inland container transport could make a reverse modal shift from water to road transport because road transport is far ahead in terms of innovation and the energy transition (Topsector, 2020). Less shipping traffic would likely also lead to less work for the Rijksrederij.

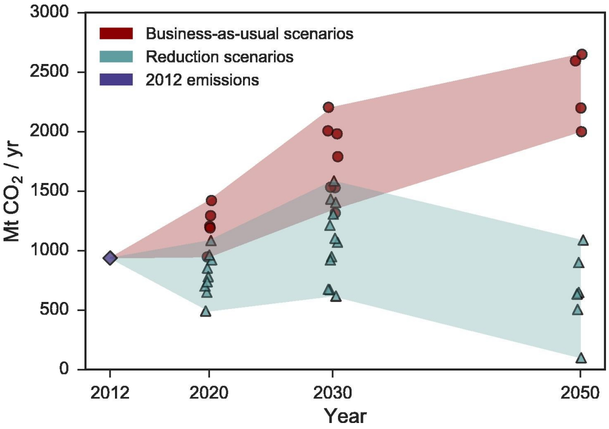


**Figure 2.7:** Annual CO2 emissions from the global shipping fleet, distinguished by business-as-usual and reduction scenario pathways (Bouman et al., 2017), illustrating the uncertainty regarding future emissions

### Pressures from climate concerns

The current goal by the IMO is to reduce 50% of CO2 equivalent by 2050 in a response to the pressure that was put on the shipping, this pressure was in part resulting from the Paris climate agreement. However, this does not mean that the pressure is taken away completely since the current emission reduction target appears to be inadequate in reaching the Paris goal. There are also studies (Rogelj et al., 2020) that suggest that the Paris agreement itself is inadequate and needs to be improved since the current Intended Nationally Determined Contributions only result in a median warming of 2.6–3.1 degrees Celsius by 2100. It is thus expected that landscape pressure to reduce emissions will persist and probably increase in the future. This will create windows of opportunity for certain niches to develop and compete with the regime, according to the MLP. Climate neutral niches are the ones that are better aligned with the changed landscape since they reduce GHG emissions. Large accidents that caused a lot of pollution have in the past resulted in a shift in perceptions about what is safe. Concerns about the Torrey Canyon accident in 1967 resulted in shipping safety legislation including the IMO's MARPOL 73/78 (Luoma, 2009). In the same way growing concerns about pollution and climate change can cause a shift in the perceptions about the use of GHG, especially after a disruptive event. This will thus be a welcome development for the Rijksrederij.

### Pressure from fuel prices

Since the vessels in the current regime run on fossil fuels the oil price has a large influence on the regime. Between 2007 and late 2012 the price of oil tripled, this increase in fuel bills has driven regime actors to improve the efficiency and even lower sailing speed (Mander, 2017). Climate neutral niches will have to compete with the carbon-based vessels, the oil price can have a large influence on which of the two in more attractive. If the oil price is high, due to market developments or artificially by means of carbon tax, it will enhance the economic feasibility of the alternative climate neutral niches. When the oil price is low it will have a negative influence on the economic feasibility of climate neutral sailing (Castro and Mestemaker, 2019).

### Increasing pressure from regime regulations

Global shipping legislation is set by the IMO, which is a specialized agency of the United nations that has the responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. Their goal is "to provide machinery for cooperation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning shipping safety, efficiency of navigation and prevention and control of marine pollution from ships" (IMO, 2020a). What is interesting here is that IMO encourages and facilitates the general adoption the 'highest practicable standards', which suggests that a new technology must first be considered practicable by the members of the IMO. Which would probably make it difficult for innovative climate neutral technologies that have not yet been adopted by the regime to become adopted by IMO regulations. Unless they have been proven in a niche.

Besides the IMO, governance and regulations in shipping can come from institutions such as the EU, national governments, ports, classifications societies or by contractual and relational forms. This makes the regulatory and governance framework of shipping complex, multiple actors and agencies can be involved in both global and local scale (Stokke, 2013). Especially for globally operating vessels, since they operate in countries with opposing interests and cultures which makes it difficult to steer and implement policy at a national level (Karahalios, 2017). The actors that can adapt existing IMO regulations and policies follow a consensus based approach which results in slow adaptation of regulations due to the large number of unaligned actors at the global level (Karahalios, 2017). The conflicting interests and actions of these regulatory institutions also harm the trust actors have in them, further limiting their capabilities (Dewan et al., 2018). Meanwhile the industry has the view that regulations regarding climate change and sulphur will be the path to innovation and change (Mander, 2017), and are thus looking at new regulations to be the pivotal driver of the transition. Local authorities probably experience a lot of resistance when they try to implement more stringent environmental regulations because local actors are afraid that it will harm the level playing field, putting them at a disadvantage in comparison with other areas. The regulatory system in the regime is thus complex, rigid and dependent on a large group of diverse actors making it difficult to steer the regime in a radically different direction. This all fits pretty well with the theory about the challenges of guiding radical low-carbon transitions of (Newig et al., 2007) from section 2.2.

### Dutch landscape developments

A future outlook on Dutch landscape influences is given by the Green Deal on Maritime and Inland Shipping and Ports (Green-Deal, 2019) which resulted from the coalition agreement of the Dutch cabinet Rutte 3. This deal has the objective to limit the emissions of harmful substances and GHG from the Dutch shipping sector which are further specified in a list of ambitions and goals.

The ambitions and goals for 2030 are: to have a reduction of carbon emissions from the Dutch inland fleet by 40% to 50% relative to 2015; to have fitted at least 150 inland vessels with a zero-emission power train and to have launch of at least one zero-emission seagoing vessel (Green-Deal, 2019). The ambitions and goals for 2050 are: to have a virtually zero-emission and climate-neutral inland fleet; to have achieved a 70% absolute reduction in carbon emissions from Maritime shipping, relative to 2008 and that climate-neutral maritime shipping will be achieved as soon as possible after 2050, and at any rate before the end of the century (Green-Deal, 2019). The parties of the green deal have set short-term goals for 2024 to achieve the ambitions for 2030 and 2050. For inland shipping: to have developed new European management instruments that will encourage achievement of the ambitions set without the government needing to lay down mandatory emission standards for individual vessels for 2030 and 2035; to achieve a reduction in carbon emissions of at least 20% relative to 2015 and to achieve a reduction in emissions of environmental pollutants of at least 10% relative to 2015. For maritime shipping: to have a reduction of the average carbon emissions per tonne-kilometer by at least 20% relative to 2008; to have further a reduction of emissions of air pollutants other than carbon, such as SOx, NOx and PM, in line with relevant international and other agreements and to have developed five new business cases for shore power for maritime shipping within the term of this Green Deal.

The parties of the Green Deal include the central government (the minister of I&W (Infrastructure and Water Management), the minister of Economic Affairs and Climate Policy and the State Secretary for Defence), provincial authorities, municipal authorities, branch associations, ports, shippers, banks, knowledge institutions (including TU Delft and TNO), energy suppliers and other stakeholders. Together they form a good representation of the Dutch shipping regime and landscape.
This Green Deal makes it clear that the end goal is to make a full transition and that this goal is supported by the government and at least a part of the sector. The timeline towards this climate neutral fleet goes until 2050 for inland shipping and until the end of the century for maritime shipping. This means that in the meantime a lot of GHG and other harmful substances will be emitted. Shortening this timeline would therefore be valuable for the environment and society as a whole. However, the Green Deal does not provide a clear plan with a pathway that should ensure that the goals are reached. How the goals and ambitions can be achieved thus seems to be unknown or disagreed upon, which indicates the importance of this research.
The Green Deal does provide a multitude of actions that should stimulate climate neutral sailing. These include numerous funds, a labeling system for inland vessels' emission performance, taxation plans to abolish the energy tax on shore power used by shipping and changing the fiscal regime for electric shipping. The ministry of IW will also strive to remove "national and international legislative obstacles to the use of alternative sustainable bio-fuels and hybrid systems in maritime shipping" (Green-Deal, 2019).
Possible EU regulations on new engines are also briefly discussed, the expectations are modest. These could include regulations that make access to the Port of Rotterdam conditional on compliance with 2025 emission standards. The ministry of I&W will also pursue the introduction of a global carbon emissions tax within the framework of the IMO. Furthermore, they will strive to establish low-emissions zones in the EU. These last two measures should stimulate climate neutral sailing while maintaining a level playing field. Multiple landscape level measures are thus discussed in the deal of which the most important ones are mentioned here. These measures can again be subdivided into hard and soft regulations.

#### The role of the Rijksrederij in the Dutch Green Deal

The Rijksrederij is discussed multiple times in the Green Deal. It is mentioned that it can play an important role: "Investment will also be needed in research into and development of new technologies, and it is important that pilot projects can be carried out on board ships. The government could play a facilitating role in this, for instance, as a launch customer" (Green-Deal, 2019). The goal of the Rijksrederij is also mentioned in the deal: "Rijkswaterstaat's climate objectives are: '20% reduction in carbon emissions by 2020, energy neutral by 2030 and fully climate-neutral and climate-resilient by 2050". Since the Rijksrederij is part of Rijkswaterstaat they will have the same objectives. Furthermore, "During the term of the Green Deal (till 2024), IW's Rijksrederij will commission three seagoing vessels powered by electric engines. These vessels will also run partly on biofuel" (Green-Deal, 2019). In article 19 of the deal it is stated that the Rijksrederij will step up its role as launching customer, share its experiences with Dutch shippers and shipowners, conduct research into alternative means of propulsion and energy carriers such as hydrogen and batteries and their financial impact with the ultimate goal of achieving a zero-emission fleet. The Rijksrederij has thus been given an important role but it is not mentioned how they are going to achieve their goals and cover for the extra costs or deal with the risks. This is remarkable since the Rijksrederij has been given an important but also challenging role in the transition.

## 2.5 Niches that develop sustainable sailing

When lock-in mechanisms are not or only partly present a niche can arise with elements that differ from those of the shipping regime. Shipping niches can be seen as parts of the sector that use new technologies or operation tactics, have no immediate objective for commercial gain due to funding, actors with a radically different mindset, etcetera. A niche can also occur as a result of a small demand for a certain type of vessel, technology or service which makes the market unstable and does not allow the development of a certain set of regime rules that create a lock-in.

The niches that are interesting for the energy transition are niches that move towards a climate neutral shipping regime. These niches can be divided into niches that try to make the existing technologies more energy efficient by relatively incremental innovations and niches that try to replace the existing technology by a radical new one. The incremental innovations niche will not lead to a climate neutral regime, and perhaps not even compensate for the extra emissions resulting from the growth of the sector. The radical niches can become a pathway towards a climate neutral sector but in general also face larger challenges. Some niche-innovations from both categories will be discussed below. For these niche-innovations it is also interesting to make an assessment of how far they are developed, for this the criteria from (Geels and Schot, 2007) that were discussed in section 2.5 will be used for as far as the available data allows it.

### Niches measures that reduce GHG emissions

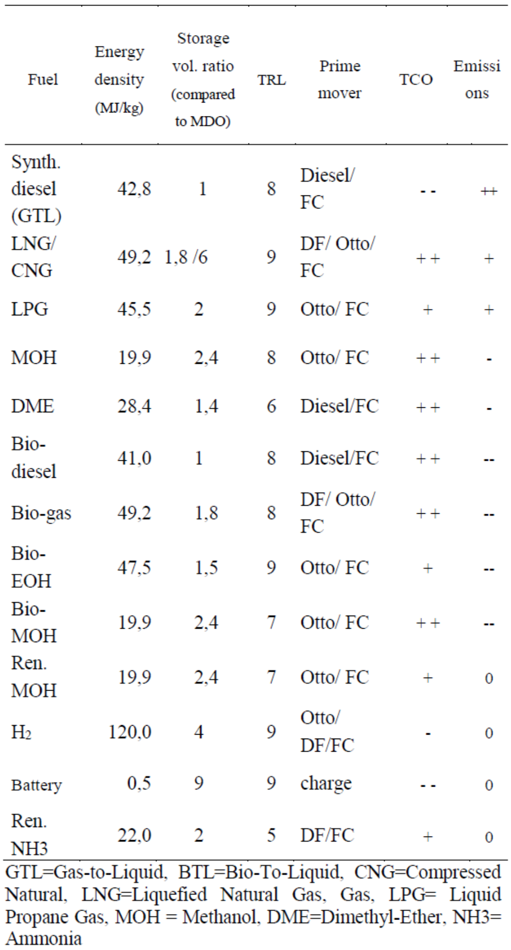
The GHG reduction potential of many niche measures has already been studied, (Bouman et al., 2017) made a review about the state-of-the-art technologies and measures. In 2.9 a graphical overview of the reduction potential of 22 measures is given, the small circles represent data points that were found in the reviewed studies which gives an indication of the level of agreement between studies. This level of agreement is not high for most studies which suggests that the articulations and adjustments of expectations have not yet converged or that they are significantly differ per sub-regime. It appears that these niche-innovations in technology, operation or infrastructure elements are generally not fully developed, although data on the market adoption rate is difficult to obtain which is an important factor. These niches can significantly lower GHG emissions when they gain momentum and become part of the shipping regime, though some measures are correlated meaning that the reduction will not simply add-up. By taking relatively uncorrelated measures such as increased vessel size, optimized hull shape, reduced ballast water, hull coating, hybrid power propulsion, propulsion efficiency devices speed optimization and weather routing an emission reduction of 78% could be obtained (Bouman et al., 2017).

Most of the presented niche innovations are however not interesting for a fleet of mostly small vessels that operate over relatively small ranges. Additionally, the figure only considers the CO2 emissions while there are more harmful emissions by shipping as was discussed in the definition of climate neutral shipping. It is also missing some alternative propulsion systems that are interesting for smaller vessels, this might be due to a lack of literature. Only fuel cells are included, although the authors state that the available data is limited and the question remains if a system could be designed in which power comes from a fuel cell (Bouman et al., 2017).

According to figure 2.9 the highest reduction in CO2 emissions can be achieved by switching to bio fuels, which are made by growing crops and are therefore traditionally assumed to be carbon neutral. However, the effects of large scale adoption could be unsustainable depending on the type of farming and the competition for scarce land resources (Cherubini et al., 2013). This might be something to take into consideration while looking at alternative energy sources for the Rijksrederij.

### Climate neutral energy carriers

The niche-innovations presented in figure 2.9 will not lead to climate neutral vessels because in most cases ships will still be using heavy fuel oil or marine diesel oil (MDO). Some energy carriers have the potential to be climate neutral, a list of these is presented in figure 2.8 which originates from a study looking for a climate neutral work vessel (Castro and Mestemaker, 2019). The alternative energy sources can be compared based on their Energy density, storage volume ratio in comparison with marine diesel oil, their technology readiness level (TRL), the prime mover (FC means fuel cell), the total cost of ownership and the emissions. This figure illustrates the fundamental challenges with climate neutral energy carriers at the moment. There are only two climate neutral options with a high technical readiness, hydrogen and batteries. For batteries the limitations lie in the costs, required storage space and weight in comparison with traditional fuels. For hydrogen the required storage volume is also 4 times as high and there are concerns about the costs, since the energy intensity required for the production of hydrogen is quite high. In (Castro and Mestemaker, 2019) a whole life cycle assessment of a hydrogen fuel cell powered



| Fuel | Energy density (MJ/kg) | Storage vol. ratio (compared to MDO) | TRL | Prime mover | TCO | Emissions |
|---|---|---|---|---|---|---|
| Synth. diesel (GTL) | 42,8 | 1 | 8 | Diesel/ FC | - - | ++ |
| LNG/ CNG | 49,2 | 1,8 /6 | 9 | DF/ Otto/ FC | + + | + |
| LPG | 45,5 | 2 | 9 | Otto/ FC | + | + |
| MOH | 19,9 | 2,4 | 8 | Otto/ FC | + + | - |
| DME | 28,4 | 1,4 | 6 | Diesel/FC | + + | - |
| Bio-diesel | 41,0 | 1 | 8 | Diesel/FC | + + | -- |
| Bio-gas | 49,2 | 1,8 | 8 | DF/ Otto/ FC | + + | -- |
| Bio-EOH | 47,5 | 1,5 | 9 | Otto/ FC | + | -- |
| Bio-MOH | 19,9 | 2,4 | 7 | Otto/ FC | + + | -- |
| Ren. MOH | 19,9 | 2,4 | 7 | Otto/ FC | + | 0 |
| H₂ | 120,0 | 4 | 9 | Otto/ DF/FC | - | 0 |
| Battery | 0,5 | 9 | 9 | charge | - - | 0 |
| Ren. NH3 | 22,0 | 2 | 5 | DF/FC | + | 0 |

GTL=Gas-to-Liquid, BTL=Bio-To-Liquid, CNG=Compressed Natural, LNG=Liquefied Natural Gas, Gas, LPG= Liquid Propane Gas, MOH = Methanol, DME=Dimethyl-Ether, NH3= Ammonia

**Figure 2.8:** Characteristics and integration aspects of various alternative fuels for work vessels (Castro and Mestemaker, 2019)

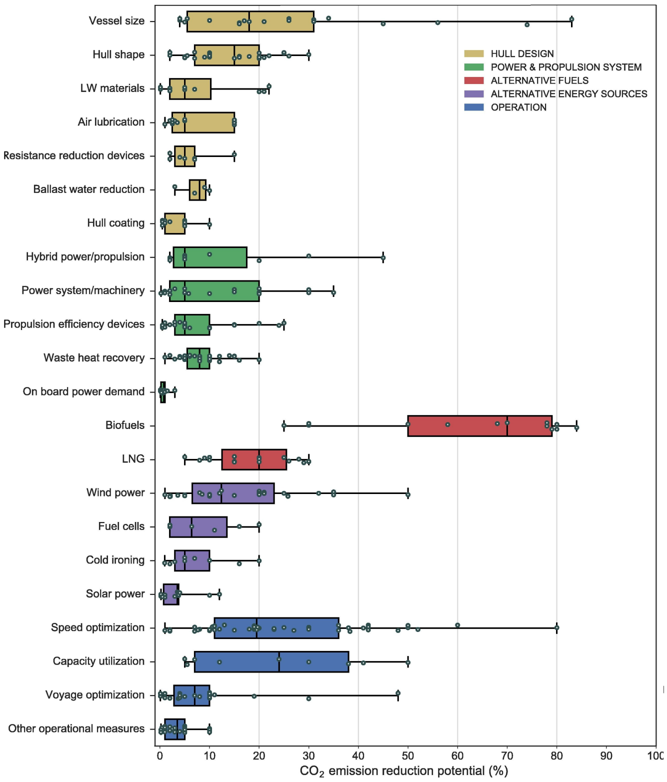
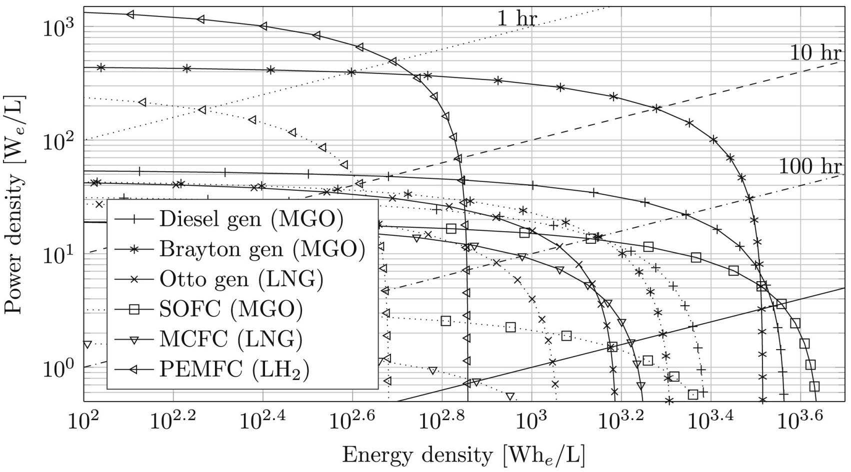


**Figure 2.9:** CO2 reduction potential from individual niche-innovations classified in 5 main categories (Bouman et al., 2017)

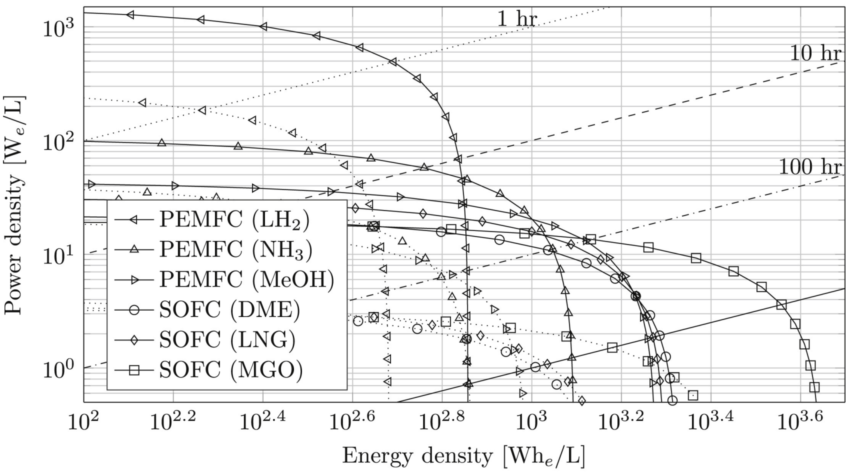
work vessel in compared to a diesel powered one, it showed that the environmental impact is reduced by more than 90%. If this is also an economically viable option for work vessels is strongly dependent on the costs of fossil fuels, emission policies and the effect of scale up on the costs of climate neutral technologies and energy carriers.

The goal of the energy transition is to move away from fossil fuels, but there is no agreement yet about what will replace the fossil fuels. Niches, which provide opportunities for learning processes, can be the ideal environment to reach an agreement. For the initial assessment of an energy carrier a ragone plot is often used, an example can be found in figure 2.10. The energy density of a power plant or energy carrier can be found on the x-axis and power density on the y-axis. Together they compare the weight that is needed to produce a certain amount of power for a certain time between different energy carriers, or the required volume if a ragone plot with volumetric power density and energy density is used. Figure 2.10 comes from an article of (Biert et al., 2016) which presented an overview of fuel cell types and fuel processing equipment for the shipping sector. Liquefied hydrogen provided a compact solution which allowed ships to sail for up to tens of hours without refueling. However, the size of the system could become five times larger than other fuel cells.

Ragone plots can give a good first indication and preliminary selection but for most systems it is difficult to get validated data from manufacturers (De Koningh et al., 2015). Furthermore, there are many more factors that determine if a certain energy carrier can be used. Multiple design criteria are discussed in a case study (De Koningh et al., 2015) that tried to design a high speed (40 km/h) inland ferry relying on a



(a) Volumetric density of various maritime power plants.



(b) Volumetric density of fuel cell systems with various logistic fuels.

**Figure 2.10:** Ragone plots of different power plants and logistic fuels, including liquid hydrogen and ammonia (Biert et al., 2016)

climate neutral energy carrier, illustrating the challenges of implementing innovative niche-technologies. For example, charging, discharging and storage of energy, which can be subject to temperature, limitations in technologies or time restrictions caused by the vessels operational profile. The life-cycle of an energy carrier can also be a challenge, for existing diesel technology there are specific rules regarding the time an engine can operate under a certain load condition while for new technologies these rules are unknown. Depending on the usage the lifetime of e.g. a battery will be 2-5 year while a comparable diesel propulsion system only needs part replacements every 12-17 years. The environmental footprint of an energy carrier is also an important factor in becoming climate neutral, a life-cycle assessment of the energy carrier and an analysis of the 'well-to-wake' path is therefore important. The capital expenditures (CAPEX) and operational expenditures (OPEX) of an energy carrier will eventually be one of the key factors in choosing an energy carrier, which are in part dependent on the state of development and regulatory policies. Finally, safety is always a concern, complying with safety standards, rules, and regulations may take extra effort when working with toxic or explosive material.

The authors of (De Koningh et al., 2015) chose batteries since hydrogen fuel cells had practical problems and local refuelling hazards. In simulations their designed vessel could only sail for 1.5 hour before running out of energy, which considerably less than the benchmark diesel vessel and did not meet the requirements. This study showed the state of development of the niche for this specific vessel and illustrates that a ragone plot alone is not sufficient but that a lot more detailed information is needed, concerning both technology and operational profiles, to design a feasible climate neutral vessel. With for e.g. pilot projects both short- and long-term properties of these technologies can be learned, which could be valuable for starting the adoption of these technologies. There are however already electric vessels on the market, such as ferries and tugs (Shipyards, 2020), but these usually have low design speeds and ranges.

#### Niches that successfully changed established ways of doing

An operational niche called slow steaming became part of the regime due to landscape pressures about a decade ago. High oil prices and the economic downturn made vessels slow down, limiting fuel consumption and soaking up over capacity in the market. This had a particularly big impact on the relatively fast sailing container carriers, between 2007 and 2012 container carriers reduced their daily fuel consumption by up to 70%, for oil tankers reduction of 50% were seen (IMO, 2014). When vessels are slow steaming they sail below their design speed, this have negative technical consequences in the form of increase fouling and corrosion in the engines due to lower operating temperatures and poor combustion (Wiesmann, 2010; Armstrong, 2013).

In response the engine manufacturing community worked and learned together, with support of established actor Maersk, to minimize the damage and set up new maintenance rules (Mander, 2017). This case shows that changes to the user practices are possible within the shipping regime, even if it disrupts supply chains and voyage times and is not positively received by many shippers (Mander, 2017). In this case the pressure from the landscape was a change in oil price and trade and not environmental considerations, but it did lead to a reduction in GHG emissions.

The niche-innovation was fully developed but depending heavily on oil price and trade, a down-swing in oil price and up-swing in trade may have taken away the financial benefits. This case could be seen as an indication that the user practices and operation of the shipping regime can change in response to landscape pressures, which would be a promising sign for the effect of possible regulations that create financial feasibility for climate neutral technologies.

A niche-innovation in infrastructure technology is Cold ironing, connecting vessels to shore based sources of power while they are in ports. This allows them to shut down their main and auxiliary engines which decreases their emissions. Since large ports are often close to large cities this can have a lot of health benefits. According to (Zis et al., 2014) these reductions can in some cases be over 50% in CO2, SO4, NOx and PM emissions. There are many of these projects and some of the largest ports in the world are working together in the "World Ports Sustainable Program" (*Sustainable World Ports* 2020). These kinds of projects can offer a space for niche actors to learn, develop, find partners and gain momentum.

Note that niches that use a climate neutral energy carrier are the only ones that are able to radically reduce shipping emissions. It appears that battery-electric powered vessels are currently the only fully developed solution since these are being produced and have standardized design, but only for a few sub-regimes. The challenge is to design a climate neutral energy system with similar energy density, power density and costs as the established diesel systems. Furthermore, is should be safe, chargeable in certain conditions, fall within the regulations and some more criteria. Niches are the only places where the possible solutions can develop, but this will not be easy.

## 2.6 Reflection: transition pathways for the shipping sector

The multi-level perspective on the shipping energy transition helps to identify the transition pathway, which is important to determine the strategy for and environmental benefits from innovators and early adopters. The regime appears to be deeply locked into the carbon-based ways of doing but is experiencing pressure from the landscape to reduce GHG emissions, the Paris agreement is a clear example of this pressure. Regime actors have responded to the landscape pressure by modifying the direction of their development path, of which the 2050 goal from the IMO is the most obvious example. However, niches with a climate neutral energy carrier are not sufficiently developed to compete with the existing regime on price and performance and replace it. The distance in knowledge between climate neutral and diesel sailing is large, which might be the reason that most actors appear to be focusing more on energy reduction measures. Furthermore, the emission reduction targets are not forcing the adoption of climate neutral sailing at the moment. It is thus a transition driven by increasing landscape pressures while the niche innovations have not yet been sufficiently developed to replace the regime, according to (Geels and Schot, 2007) this transition follows the transformation pathway which is illustrated in figure 2.11 and was described in section 2.2.

The transformation pathway transitions are characterized by criticism from outside the regime on the incumbent rules, followed by a reorientation of the development trajectories of regime actors. A new regime slowly grows out of the old one by gradual adjustments in regime rules and perceptions. Knowledge about the new technologies will have to be imported from outside the regime, adjusted and developed to create a niche that can compete with the regime. Adaptability of regime actors, policy and regulations are important in this transition. Since incentives to adopt niche innovations from within the sector are likely to be small, they should come from societal pressure on governing structures, ship owners, ports and other actors that have an influence.

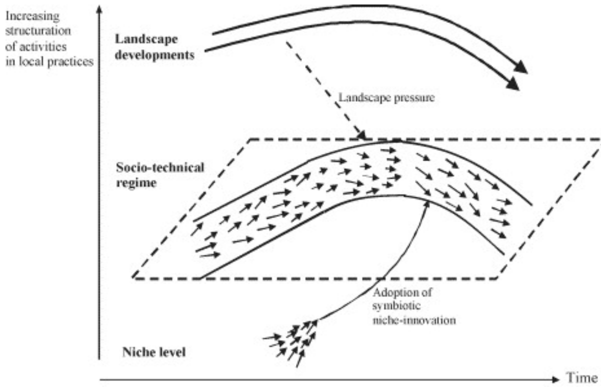


**Figure 2.11:** Transformation pathway (Geels and Schot, 2007)

### Steering the shipping energy transition

The energy transition of the shipping sector will be a goal-oriented steered transition, as was explained in section 2.2. This steering can be done by certain regulations, innovators and early adopters. The interests of the actors in the regime will in many cases not line up with the interest of the climate. This will make steering in a radically different climate neutral direction difficult. Most actors are not interested in showing leadership in the transition (Mander, 2017) or might even work against it because of their mindset or interests to maintain the existing regime.

The stakes can be high when it comes to the pathway of the transition. The diffusion rate, sequence and used technologies will have a large impact on almost all actors in the shipping sector. Some will have large sunk investments in certain new or old technologies and energy carriers that they are looking to protect. Some actors have an interest to slow the transition down, such as suppliers of fossil fuels or an engine supplier that has invested in LNG technology believing that it will be a step between diesel and climate neutral. The more advanced ship production companies might profit from new and innovative climate neutral technologies and are looking to speed up the transition as much as possible. Profits or losses of billions of dollars will depend on the pathway, therefore it is to be expected that actors will try to influence and steer the path in a certain way.

Without regulations and policies that steer the regime towards a transition the interest in climate neutral sailing will be low since there is no clear incentive. Climate neutral technologies have no obvious user benefits, are unaligned with the regime elements and score in general lower on price/performance dimensions. The climate is a common good, which leads to free rider problems and the prisoner's dilemma. Individual actors do not profit from protecting this common good because the price and performance are not competitive, but if the common good is not protected it will deteriorate and the entire society will suffer. The landscape pressures, coming from authorities and the society as a whole, try to protect the common goods. This could be seen as a response to the lack of responsibility that is taken by the sector, caused by a lack of incentive.

The landscape pressures stimulate policy makers and regulators to steer the sector towards an energy transition. Policies and regulations could make changes to the regime that improve the price and performance of climate neutral technologies in relation to the established technologies. This would create an incentive to develop and adopt the climate neutral technologies, which protects our common good, the climate. This could be done by e.g. taxes, subsidies or emission limits. Such steering policies are difficult to adopt since it has such an enormous influence on all actors of the shipping sector. Even without these actors it would be difficult to determine the transition pathway that is most desirable because of the complexity and uncertainty of transition elements such as technology, policy and public opinions. The governing structure is complex and there is no all-powerful actor. As a result, the current regulations are not adequate in preventing climate change, which is not likely to change in the near future.

Actors themselves can also steer the direction by becoming innovators or early adopters of climate neutral technologies. They can establish niches which are strengthened by landscape pressures and subsidies. Within these niches many development processes can take place that allow climate neutral niche elements such as technology, infrastructure and ways of doing to co-evolve, as was described in sections 2.2, 2.2, 2.2 and 2.2. Because of the developments and high landscape pressures these niches could than start to expand and gain momentum. Eventually they could start to influence the regime by bringing it innovations and new rules and perceptions.

The transition will thus be driven by landscape pressure that pushes actors in the direction of a transition. The path of this transition will depend on the landscape pressure, policies that respond to this pressure but also on the influence of actors in the regime. The input of actors can be crucial in this transition, since radically different policies are not expected due to the difficult regulatory framework. The sectors willingness to adapt, invest and adopt are going to be crucial for both regulations and technology. Based on literature it seems that there are some examples of actors that are willing to lead, while the majority maintains a conservative mindset. The leading actors will become the innovators or early adopters as defined by (Rogers, 1996). The more conservative ones will become the early majority, late majority or laggards.

#### Transition sequence

The shipping sector is quite diverse in types of vessels, business models and organizations. The vessels differ in operations, size, range, design speed, costs, needed supporting infrastructure, etcetera. The regulations and policies differ per operational area and ship type. The economic feasibility of an energy transition depends on the operations and the perceived value of a climate neutral service. There is probably also a differentiation in the mindset towards the change in general among organizations in the shipping sector. All these different aspects influence the strength of the lock-in mechanisms. Thereby it also gives an indication of the readiness for the energy transition of different sub-regimes and organizations. Lock-in mechanisms will probably disappear in a certain sequence over time as a result of innovations and landscape pressures. The differentiation in the aspects will therefore also lead to a certain energy transition sequence.

The niches that have the weakest lock-in mechanism will be the optimal place for climate neutral sailing to develop. With subsidies, partnerships, and strategic niche management a safe place can be created where by doing, using and interacting the technologies can be developed. These niche development projects could also help with implementing regulations that makes climate neutral sailing more competitive, by providing clear data on price and performance dimensions. When a climate neutral 'way of doing' becomes financially and operationally feasible it can start to compete with sub-regimes that have similar aspects. The momentum that is gained in niches can be used to break through the lock-in mechanisms and change the 'ways of doing' in sub-regimes. The transition will then start with niches that have the most favorable conditions, followed by sub-regimes that have the most favorable conditions followed by sub-regimes with increasingly less favorable conditions.

An overview of these conditions for the Rijksrederij and two reference sub-regimes is presented in table 2.1 as an illustration of how the feasibility of an energy transition can differ. The inland ferries sub-regime is chosen because it is estimated that the conditions are relatively similar to those of the Rijksrederij. The global container carrier sub-regime is chosen to make a comparison with a larger sub-regime for which the energy transition is currently far more difficult. This is due to the size and costs of the assets and the complex global system they operate in which for example subsidies of the required magnitude are difficult to obtain. The conditions are based on the results from the MLP analysis in this study. The landscape pressures all vessels to make a full transition, however the pressure on the Rijksrederij leads to a stricter goal than the pressure on global container carriers. This can be explained by looking at some of the regime conditions which can make a transition more or less feasible. The table also looks at conditions that are relevant for establishing a climate neutral niche. When assessing the conditions of the Rijksrederij they appear to be in a favorable condition for the energy transition, which is to be expected given their ambitious plan. Note that the table does not contain validated data. This is however not needed to illustrate how the MLP can be used to assess the feasibility of a transition for multiple sub-regimes.

| **Socio-technical level** | **Barriers that might apply** | **Rijksrederij** | **Inland Ferries sub-regime** | **Deep sea container carrier sub-regime** |
|---|---|---|---|---|
| **Landscape** | Governance framework does not stimulate the transition | + | + | - |
| **Regime** | Strongly embedded regime due to sunk investments and strong status quo in vessels and operational practices | + | + | - |
| | Actors are unable to make the required investments in new technology and infrastructure due to low production quantity and strong competition | + | + | - |
| | Actors are conservative, inward focused and only interested in commercial gain | + | + | - |
| | There is no incentive for sustainability in the business case | + | + | - |
| | There is a lack of competence and awareness regarding sustainable shipping | + | - | - |
| **Niche** | Too much uncertainty about performance climate neutral technology due to low TRL | + | + | - |
| | Unable to cover additional costs | + | - | - |
| | Regulatory market entry barriers due to lack of classication and operational rules | - | - | - |
| | Not possible to supply vessel with climate neutral energy carrier in operational area | + | + | - |

**Table 2.1:** Table illustrating the feasibility of an energy transition for the Rijksrederij and two sub-regimes based on the multi level perspective. The entries to this table are estimations made by the author. A + means positive/feasible conditions, a - means negative/not feasible conditions.

Because of the wide range of operational profiles and thus technical requirements of the vessels in the shipping industry multiple technologies and innovations might be necessary for a sector wide energy transition. The scale up perspective for a technology like batteries is limited due to its unfavorable power and energy density, ammonia might have a higher scale-up perspective but is in a lower state of development. Therefore, it is wise to invest in multiple niche-technologies which each have a scale-up perspective for a different part of the shipping regime. Each will follow its own development process and adoption sequence, leading to multiple adoption curves as is illustrated in the three S-curves in the adoption graph visualized in figure 2.12.
The S-curve illustrates that the adoption will start of slow, gain momentum as the early adopter join in and then take off. The time to full adoption will differ per innovation. In reality this adoption of different niche-innovations is likely follow a non-linear path, as was discussed in section 2.2. Furthermore, a climate neutral 'way of doing' will only be suitable for a part of the regime and therefore not reach 100% adoption. The energy transition will thus rely on the development of multiple new 'ways of doing' with their own development pathways, scale-up perspective, adoption sequence and adoption timeline.

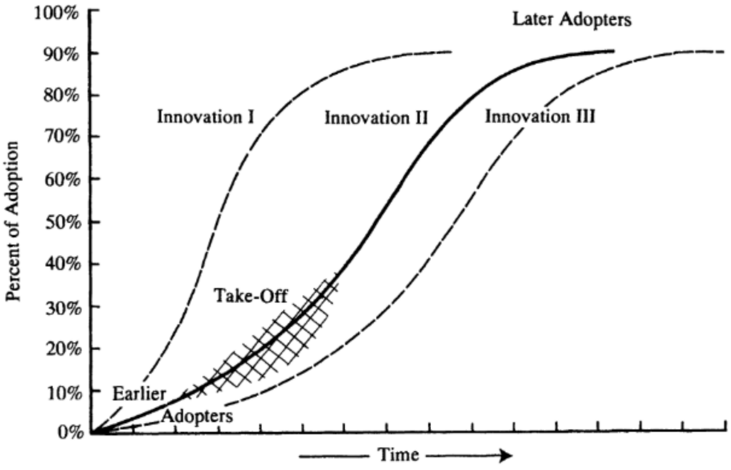


**Figure 2.12:** Diffusion of multiple innovations (Rogers, 2010)

**Limitations of a literature study**

Many actors in the shipbuilding community are probably investing in the development of climate neutral propulsion systems in response to landscape pressures, since this can become a large market in the future. However, some of them will not publish any articles or other literature about the performance of their innovations to protect them from being copied by competitors. Although for others publishing about their progress might be a way to get funding for further research, for which it would be wise to focus on the positive results. The actual performance of niche innovations is to some extend also unknown until it is tested in an operational environment, by doing using and interacting. It is thus questionable if one can obtain a holistic overview of climate neutral shipping niches by a literature study, since the limited information that can be found might not represent the reality.

## 2.7 Rijksrederij

The Rijksrederij has the goal, set by the ministry, to become climate neutral in 2030. They will have to deal with many lock-in mechanisms in the shipping sector and become an early adopter if not innovator of many new niche 'ways of doing'. Even though they are in a more favorable position than many other ship owners it will still be a tremendous organizational and technical challenge. Dealing with this challenge probably deviates from their normal day to day work and requires cooperation with new partners. These will be experts in science, technology and innovation like TNO, Marin, TU Delft or engineering firms. The actors that build, operate, maintain and supply their vessels will also play a vital role. For stable and reliable operation of the climate neutral fleet, which is important for the success of the energy transition at Rijksrederij, the niche should grow into a sub-regime.
Pilot projects can become the first step towards a regime since they will be safe spaces where the niche learning processes can take place. The impact can be optimized by choosing technologies with different scale-up perspectives and implementing the SNM theory form section 2.2. Partners can further improve the impact, such as the police or the navy or perhaps shipowners that operate vessels with similar operational profiles such as inland ferry companies. They are probably able to join the climate neutral sub-regime relatively easily when this has been established. When multiple owners combine their efforts together in a global overarching network the community and the developments of pilot projects will be strengthened. This will help to stabilize the niche and prevent non-liniearity as described in section 2.2. The community could be further strengthened by activities such as conferences, webinars, workshops, newsletters, etcetera.

Although the Rijksrederij has no competition in their line of work they do have to justify their expenses and investments to their clients. These clients might be more interested in satisfactory operation within the limits of their budget than in stimulating the energy transition, just like most actors in the shipping

regime. Maybe some employees at the Rijksrederij itself will also feel resistance towards the energy transition. Justifying their plans to all employees and other partners will thus be important.
Since the Rijksrederij is a governmental organization they have to deal with certain procurement and outsource policies. These policies should ensure that no company is favored over others to prevent corruption at the government. This can become an extra challenge in the energy transition, since the Rijksrederij will have to work together with many other companies and outsource some of the work. Comparing these companies with verified data on what they can deliver will be challenging.

## 2.8 Research methods collected during the literature study

In (Mander, 2017) an multi level analysis is made of slow steaming and wind propulsion, this was done by conducting semi-structured interviews. Eight industry experts participated in this study and shared their knowledge to gain in-depth knowledge on the niches. The interviews were transcribed and analyzed qualitatively using Atlas-ti. This software program enables researcher to structure the knowledge and identify the emergent themes. These were technology development within a protected niche, required changes to the regime that are necessary to let the niche become mainstream and the role of the external landscape.
In (De Koningh et al., 2015) a concept design case study is used to understand the energy carrier selection and design process of a vessel given an operational profile. A GPS tracker was used to understand the operational profile which was translated to engine and energy carrier requirements. This method is more practice-based and identifies all the technical and operational requirements of new technology and the barriers that emerge. Such a method could also be used to identify the development trajectory and the partners that are required for successful operation of a climate neutral fleet.
A concept design is also used in (Castro and Mestemaker, 2019), but this paper uses the concept design for an environmental and economic assessment rather than a technical one. For these assessments a Life Cycle Assessment tool is used which is developed by the EU-funded project Joules. This project also funded the (De Koningh et al., 2015) paper.
In the study of (Lannes and Logan, 2004) a computer based questionnaire for employees of shipbuilding companies was used. The objective was to understand how innovation was viewed and to determine specific behaviors that are critical for innovation according to employees. Computer based questionnaires can thus be used to determine the mindset and prevailing cognitive rules in a sector.
The study of (Makkonen et al., 2013) also used a questionnaire but they used telephone interviews to gather their data. These interviews were conducted with employees that held an executive function at a shipbuilding company, they obtained data from 148 companies. Answers were mostly given as opinions on a scale of 1 to 7 (1=low, 7=high). The Questions covered a wider range of topics such as innovative activities, strategies, and the resources of firms.
Theories like the MLP (Geels, 2002), Dolata's sectoral change model (Dolata, 2009) and strategic niche or innovation management (Geels and Raven, 2006; Geels and Schot, 2007; Rogers, 1996; Jensen et al., 2007) can be used to determine transformation pathways and substantiate strategies.

## 2.9 Recap and conclusions

The multi-level perspective on socio technical transitions is based on the idea that a transition is a non-linear process that results from interactions and developments on three analytical levels: niches, socio-technical regimes and the exogenous socio-technical landscape (Kemp et al., 1998; Geels, 2002). These three levels were analyzed with both transition theory literature and maritime specific literature.

### Transition barriers

The MLP argues that actors have shared beliefs that make actors blind for developments outside their scope, shared capabilities and competences by shared education, deeply embedded user practices, institutional arrangements, regulations and market entry costs that create market entry barriers, etc. (Geels, 2012; Geels, 2011). This creates certain shared 'ways of doing' which creates stability and path-dependency to a level that only incremental changes are possible, radical systemic changes will thus not come from within the regime. The regime consists of socio-technical elements: technology, infrastructure,

market and user practices, regulations and mindset, which are strongly aligned with each other.
The variety of vessels, operations, operational areas and organizations in the Dutch shipping cluster creates sub-regimes, e.g. a yachting, container carriers, inland work vessels or a crude carrier sub-regime. The shipping transition barriers that create the before mentioned lock-in are summarized in table 2.2.

| Regime elements | Regime Barriers; barriers that slow down the energy transition |
|---|---|
| All | The cluster is strongly embedded and aligned with the existing regime elements (Geels, 2002), this is strengthened by the amount of capital that is invested in carbon-based technology and infrastructure (Pettit et al., 2018) |
| Technology | There is a strong status quo in vessel design and the used technologies, actors prefer this because it ensures reliability (Gilbert et al., 2014) (Wijnolst and Wergeland, 2009) |
| Technology | Vessels are built in small series, first one has to work and engineering cost can not be spread out which limits innovation (Wijnolst and Wergeland, 2009) |
| Mindset | Actors have an inward focus and are not interested in solving climate change (Mander, 2017) |
| Mindset | Actors have an conservative mindset and are not interested in change in general (Mander, 2017) |
| Mindset/ Markets and user practices | Actors are, and can only be, interested in commercial gain because of tough market competition (Psarros and Mestl, 2015) |
| Market and user practices | In charter business cases there is no incentive for sustainability because shipowner does not pay fuel costs (Mander, 2017) |
| Market and user practices | Actors have a lack of knowledge, competence and awareness regarding sustainable shipping practices (Dewan et al., 2018) |
| Regulations | Actors are waiting for rules and regulations to stimulate and steer the transition (Mander, 2017) |

**Table 2.2:** Regime barriers in literature

The socio-technical shipping landscape consist of external elements such as oil or hydrogen price, macroeconomic trends, politics, spatial structure such as canals, environmental concerns or external technological developments. Changes in these elements can put pressure on the existing socio-technical regime and steer it in a certain direction (Geels, 2011). This pressure will be important in the energy transition of shipping since the niches are not yet fully developed and the regime experiences major transition barriers. Hard and soft regulations can be used to steer the shipping sub-regimes towards a transition and stimulate the development of climate neutral sailing, which will be important to increase transition feasibility. There are however also barriers for the implementation of these policies, which are summarized in table 2.3.
The Dutch Green Deal on Maritime and Inland Shipping and Ports included launching customership by the Rijksrederij as one of the steps that brings the transition closer. However, it did not substantiate what the added value was of such a project or how the project could get past the transition barriers.

| Element | Landscape Barriers, barriers that slow down the implementation of a radically different regulatory framework |
|---|---|
| Landscape dimensions | Uncertainty about future price and performance dimensions, social acceptance, consumer interest and policy's and most desirable solutions (Newig et al., 2007) |
| Governance framework | Complex governance framework, multiple unaligned actors on both global and local scale (Stokke, 2013), no all powerful actor |
| Governance framework | The uncertainty in relation to the 'level playing field' due to (international and multi modality) interdependency. |
| Governance framework | Landscape actors have a lack of knowledge and competence regarding the energy transition |

**Table 2.3:** Landscape barriers in literature

Niches with radically different 'ways of doing ' can be established when the lock-in mechanisms are less pronounced, they form the seeds for systemic change. These niches form 'protected spaces' where learning processes can occur, social networks can be built and the expectations and visions on novel practices can converge (Kemp et al., 1998). A climate neutral shipping niche can be established when a group of actors launches a vessel that runs on a climate neutral energy carrier. There are barriers for such a project, which are summarized in table 2.4.

| **Niche Elements** | **Niche Barriers, barriers that slow down climate neutral niche development** |
|---|---|
| Technology | The uncertainty about performance of niche technology (Bouman et al., 2017) |
| Technology | Low technological readiness level for some energy carriers (Castro and Mestemaker, 2019) |
| Technologies/Regulations | The CAPEX of climate neutral vessel too high to stay competitive (De Koningh et al., 2015) |
| Technologies/Regulations | The OPEX of climate neutral sailing too high to stay competitive (De Koningh et al., 2015) |
| Mindset/ Markets and user practices | Climate neutral actors are unaligned, there are no 'rules of the game' that can be followed (Geels, 2002) |
| Regulations/ Markets and user practices | No certification, regulation and education available for climate neutral sailing (Geels, 2012) |
| Infrastructure | No supportive infrastructure available, e.g. no hydrogen bunker options (De Koningh et al., 2015; Castro and Mestemaker, 2019) |

**Table 2.4:** Niche barriers in literature

### Transition enablers

The barriers and developments on the three MLP levels are expected to lead to the transformations pathway which has three transition enabling developments, increased pressure from the landscape, reorientation of the regime development trajectories and the development of climate neutral shipping practices in niches. These developments will lead to a gradual transition with multiple climate neutral energy carriers and a certain transition sequence due to differences in transition feasibility across the sector.
Launching customers can establish climate neutral niches when the transition barriers are less pronounced, creating possibilities for significant transition enablers. These are summarized in 5.3. aunching customers can establish climate neutral niches when the transition barriers are less pronounced, creating possibilities for significant transition enablers. The development trajectory, management and learning modes of niches can substantiate the strategy of launching customers (Geels and Raven, 2006; Jensen et al., 2007; Geels and Schot, 2007). This is an important first step in answering the research question but, detail, depth, context, verification and the application to the specific case of the Rijksrederij is still missing.

| **Niche Elements** | **Benefits of climate neutral niche development; enabling the energy transition** |
|---|---|
| Technology | Creating opportunity for radical innovation, the seed for systemic change (Geels, 2002) |
| Technology | Articulation and adjustment of expectations and/or visions (Kemp et al., 1998) |
| Technology/ Regulations | Building social networks and expanding social resource base with powerful actors (Kemp et al., 1998) |
| Technology/ Regulations | Get rid of imperfections within elements (technology, infrastructure, etc.) and converge towards a stable design with standards (Kemp et al., 1998) |
| Mindset/ Markets and user practices | Improve price and performance dimension (Geels and Schot, 2007) |
| Regulations/ Markets and user practices | Put pressure on the regime (Geels, 2002)(Geels et al., 2017) |

**Table 2.5:** Transition enablers resulting from niche development

### Gaps in literature

The literature on the shipping energy transition mainly focuses on the globally operating merchant fleet, e.g. (Bouman et al., 2017), including the ones using a socio-technical approach, e.g. (Mander, 2017) and (Pettit et al., 2018). This is however not the part of the shipping sector the Rijksrederij operates in and for which the energy transition is the most feasible in the near future. The characteristics of the landscape, regime and niches of this part of the shipping sector seem to be currently missing in literature. The theory from (Geels and Raven, 2006) about niche development and the theory about the importance of doing using and interacting in this development (Jensen et al., 2007) are also not applied on climate neutral innovation in this sub-sector. Studies using these existing theories could be used to better understand the transition path of this sub-sector and to determine a strategy on how to build a climate neutral niche out into a regime with multiple shipowners. It could be possible that the existing theories need to be adapted to make them fit with the energy transition of this specific sub-sector.

The literature on the transition pathway of the shipping sector focuses mainly on certain regulations, policies and technologies and not on a transformation path as was discussed in this study. The lock-in mechanisms and complex structure of the regulatory systems and a lack of incentive at many shipowners will be an issue for most of the pathways found in literature. Organizations that show leadership by becoming an early adopter of a climate neutral fleet can also have a significant positive impact on the transition pathway, this is a subject that is currently missing in literature. Stimulating adaptability, innovation and a sustainable mindset will also be important for the shipping energy transition. The energy transition at the Rijksrederij could be a good case study to proof this.

A well established theory on the diffusion of innovation is the one from (Rogers, 1996), on which multiple more detailed approaches have been developed. For example, elements that influence the rate of diffusion: the innovation itself, communication channels, time, and a social system. For the diffusion of climate neutral vessels in the shipping sector this theory does not seem to be applicable. Based on the lock-in mechanisms that were identified in this literature study other elements are more likely to determine the rate of diffusion, e.g. the elements that were discussed in table 2.1. A theory that can explain the rate of diffusion of climate neutral sailing in the shipping sector and the sequence of adoption is currently missing. This would be valuable for making project plans and determining the right strategies and policies for both governments and organizations. A matching cost-benefit method to assess the effect of certain policies and actions on the rate of diffusion would also be use full for this. This would also be a step to determining the environmental benefits

## 2.10 Recommendations for further research

Many transition barriers were found in literature but it is not clear which of them apply to the Dutch shipping cluster and specifically to the Rijksrederij. Furthermore, some might be missing in the current overview. Therefore, it is recommended that further research is done into the transition barriers for these specific cases.

Specific theories on the development, management and resulting transition enablers from shipping pilot projects was not found in literature. It would be of great value for the transition to develop this knowledge for pilot projects in general and specifically the Rijksrederij.

A climate neutral shipping sub-regime will consist of multiple elements: the prevailing technology, policy and regulations, market and user practices, infrastructure and mindset. These will however not suddenly change across the entire sector. It would be interesting to study which actors could join the regime, at which moment in time, what their barriers for joining are and what they can contribute. If a transition is technically and operationally feasible for the Rijksrederij by 2030, it will also be feasible for many other shipowners in the Netherlands. This information will be helpful for creating a plan on how to make the sub-regime stable, growing, and economically and operationally feasible.

It is clear that the Rijksrederij will create environmental benefits with their transition because they will be stimulating climate neutral innovation, lower barriers for others and adopt climate neutral technologies themselves. However, further research should be done on to try and quantify their environmental benefits.

# Chapter 3

# Solution Design

The aim of this chapter is to provide the research approach for answering the research questions based on the developed theoretical framework. The multi-level perspective on socio-technical transitions provided the framework for the literature study, this will be adjusted so that it better supports the energy transition of the Dutch shipping cluster in section 3.1. Both explorative and quantitative methods to further research the transition barriers, enablers and the value of pilot projects will be discussed next in sections 3.2 and 3.3. The chapter ends with the research approach in section 3.4.

## 3.1 A multi-level perspective on the Dutch shipping energy transition

The theoretical framework found that the shipping sector can be conceptualized as a cluster of socio-technical sub-regimes rather than a single socio-technical regime, because of the large diversity in the sector. These sub-regimes are locked into fossil fuels, but these lock-in mechanisms are not equally stringent in the different sub-regimes. The diversity will also lead to different requirements for climate neutral alternatives, which is expected to lead to multiple niches based on different energy carriers focusing on different parts of the cluster. It was also found that the transition will follow the transformation pathway, since it is driven by landscape pressures while the niches have not yet fully developed. This pathway relies on the landscape to change in favor of climate neutral sailing, regime actors to reorient their development trajectories and niches to bring new 'ways of doing' to the regime level, where they will then be adopted by regime actors. This is all incorporated into a new framework that is is visualized in figure 3.1 and will be discussed in detail below.

### The Dutch cluster of socio-technical shipping sub-regimes

At the regime level the socio-technical Dutch shipping regime is visualized as a cluster of different sub-regimes that are interconnected. Sub-regimes consist of the socio-technical elements: technology, infrastructure, mindset, market and user practices and regulations (Geels, 2012). These elements are all aligned within a sub-regime. Sub-regimes themselves are also aligned with each other but have differences in vessels, operations, operational areas, level of structuration and other elements. The cluster of sub-regimes can be found relatively high on the left side of figure 3.1, since it is quite a structured regime and exists in the present time. The sub-regimes of the Dutch shipping sector are based on the different operations that bring their own 'rules of the game', such as shrimp fishing, inland container transportation, deep sea dry bulk transportation, river cruises, inland dredging, etcetera. These each have actors such as customers, shipowners, shipyards, engineers, regulations and ports that are aligned with their specific 'ways of doing'. These actors can however be active in multiple sub-regimes. The goal of the energy transition is to make this entire cluster climate neutral, the challenge is to overcome the transition barriers which differ per sub-regime.

The literature study has already given an overview of transition barriers that slow down the energy transition of the shipping cluster, which are summarized in table 2.2. These barriers are categorized on

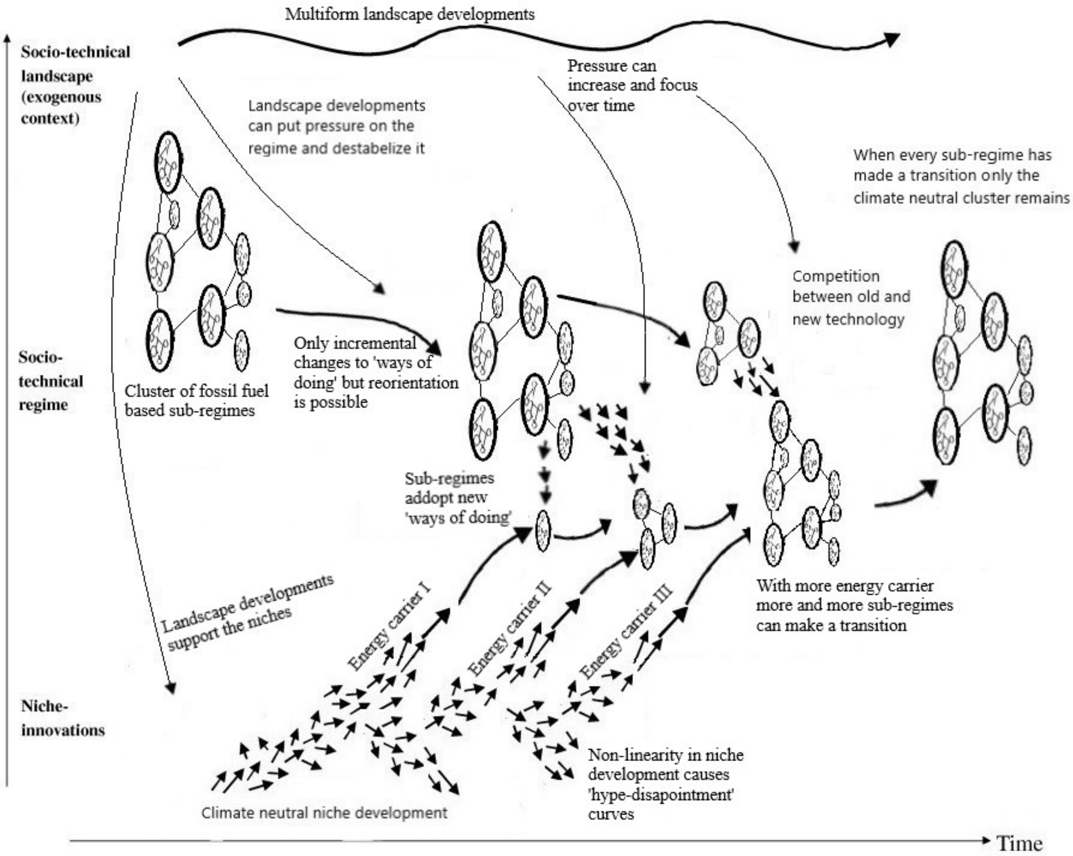


**Figure 3.1:** Sketch of the Dutch shipping energy transition based on the multi-level perspective

the socio-technical regime elements they relate to. There are differences between sub-regime elements, for example the infrastructure, regulations and mindset of the deep sea container carrier sub-regime is likely to be different from the deep sea cruise ship sub-regime. They might therefore not experience the same barriers, while they use the same diesel engine technology. When one of these barriers or a combination of them apply to an organization a transition will be difficult in the near future. Taking away any one of these barriers for an organization can bring the transition a bit closer, a transition enabler that shortens the transition timeline. However, the barriers that apply to the different parts of the Dutch maritime cluster first need to be identified and verified to understand which barriers need to be taken away by transition enablers.

These transition barriers will probably make a transition difficult, if not impossible, for the Dutch shipping cluster. However, a reorientation of the development trajectory as described by the transformation pathway might already be possible. This could support the niches and improve the adaptability of the cluster. This reorientation of the sub-regimes is illustrated by an arrow pointing from the regimes towards the niches in 3.1.

### The Dutch exogenous socio-technical landscape

Landscape actors are important in the transformation pathways since they put pressure on the regime by drawing attention to negative characteristics and changing regulations. This can open up windows of opportunity for the climate neutral niches, especially when they are supported by the landscape. Landscape influences are multiform, they include environmental concerns that destabilize it, growing demand for transport that pushes it to grow and the prices of energy carriers that influences the competition between climate neutral and carbon-based technology. However, the most significant are the changes to the regulatory framework that shape the regime, since this is a goal oriented transition that will not

emerge from within the regime but requires 'steering' from outside the regime.
Future regulations will therefore have a large impact that can be transition enablers that lead to large environmental benefits. At the moment the concerns about climate change and pollution only seem to lead incremental changes over time but not to a full transition. This could be changed when landscape actors implement regulations that radically changes the price of climate neutral sailing compared to the established 'ways of doing'. This is crucial since climate neutral sailing might never become market ready without this regulation, due to the costs. The landscape can thus put pressure on the regime, support the niches and influence the competition between niche and regime 'ways of doing', which is all illustrate by arrows in figure 3.1. The multiform and non-linear development of the landscape is illustrated by the arrow at the landscape level.
In the Dutch shipping sector the IMO, EU and Dutch government are all able to influence the regulations, although power can be limited due to the interdependency as was discussed in the theoretical framework. They are hypothesized to operate at the landscape level due to their distance from regime level actors, although they might be influenced by them. It is also hypothesized that local authorities, such as the Dutch government, should be able to implement radically new legislation as long as it does not hurt the level playing field. This will however only happen if it is on the agenda of the Dutch government, which depends on the public opinion, since the government is democratically elected. Therefore societal concerns about the environment and their views on the Dutch shipping sector should be able to influence the adoption of radically different legislation that stimulates climate neutral sailing.
If the Rijksrederij could stimulate new regulations that support or even favor climate neutral sailing it would be a transition enabler that can lead to large environmental benefits, since it would shorten the transition timeline. However, according to the literature study there are some barriers for implementing a new regulatory framework, these are listed in 2.3. They are divided in two categories from which they arise: the governance framework or uncertainty in future landscape dimensions.

### Dutch climate neutral niche development

Climate neutral niche development is visualized by the arrows at the bottom of figure 3.1. This will be the seed for systemic change since they can develop new 'ways of doing'. The multitude of arrows illustrate the multitude of sustainable research and development projects that will be undertaken in the shipping sector. Many of these projects are independent and not well aligned with other projects, therefore they have their own short development trajectory. When they are followed-up by new projects the niche can develop and gain momentum, with the help of learning processes (Kemp et al., 1998) and strategic niche management (Geels and Raven, 2006) as described int the theoretical framework. These projects will become increasingly structured and are therefore moving up. Pilot projects can play a crucial role in the development of niches by which they create transition enablers that can lead to environmental benefits (Geels and Raven, 2006). However, the development of niches is non-linear (Geels and Raven, 2006) and some the projects will fail, which is illustrated by arrows going down.
It is expected that multiple climate neutral technologies will be used in the future, each with their own 'rules of the game'. The characteristics of a sub-regime will determine which energy carrier will be the best fit. These different energy carriers will have their own development trajectory, which is visualized by the three niches moving upwards from the niche level to the regime level, based on the adoption curves in figure 2.12. A multitude of climate neutral niches is being developed as a result of the multitude of vessels and operational profiles that have different requirements. When a niche is fully developed it can grow out into a sub-regime, but only when there is group of actors that is willing to adopt the niche 'ways of doing'. It appears that for most commercial organizations there is no obvious short term financial gain in developing the climate neutral niche. It will thus be difficult to find organizations that are willing to be launching customer, while they are crucial for the development of the niche. Organizations can be motivated by publicity, an improved image or by prospects of large gains in the long run, when they manage to get ahead of their competition. A launching customer project already requires a multitude of actors from such as a shipowner, shipyard, engineering firm and energy supplier. These actors have to align themselves with the changes in the socio-technical elements.

A climate neutral cluster can be established when multiple actors from different sub-regimes become aligned with the new climate neutral niche elements, the new 'rules of the game'. A niche grows out into a regime when it becomes a stable community with established rules, the 'rules of the game' and grows in size. Establishing a climate neutral sub-regime will require investments in e.g. vessels, infrastructure

and people, which can be risky as long as the development trajectory is uncertain. It will also further align actors and create a stable demand for the services and energy carriers that are required for the sub-regime. This can only be achieved when there are no significant barriers in the way and the actors closely work together and the niche is supported landscape and regime actors.
Once a climate neutral sub-regime has been established operations will become considerably more reliable because the regime elements and actors are aligned again. This will also improve price and performance dimensions because of the larger scale and further developments in knowledge and experience. Therefore a wide range of transition enablers can be created in this process. However, the costs for an organization like the Rijksrederij will also go into the hundreds of millions since retrofitting and replacing a fleet of 100 vessels is expensive and requires a lot of expert knowledge. When more and more organizations make the transition to the climate neutral sub-regime it can eventually replace the sub-regime, which is visualized in figure 3.1.

When the barriers from table 2.2 do not apply to an organization it does not mean that a transition is already feasible for an organization. The possibility to become a leader in the shipping energy transition depends on the barriers for climate neutral niches, which are listed in table 2.4. This table is also based on the literature study. Some organizations have a business case in which it is feasible to pay a lot for the transition, while the room for extra costs might be marginal for others. Launching customership in the shipping energy transition has its own feasibility barriers which again differ per organization. When there is no infrastructure to supply climate neutral energy carriers, such as hydrogen, to a vessels operational area it will be difficult to make a transition. Setting up a supply chain and building the needed infrastructure for bunkering hydrogen will be an operation that is too complex for almost, if not all, Dutch shipowners. This will require an energy supplying organization with experience and the capacity to develop the supply of climate neutral energy carriers, and make investments. Note that, an energy supplier might not be interested in developing the infrastructure as long as there are no vessels that create a demand for hydrogen. This is a deadlock situation which can be solved when shipowners commit to a future demand and find an energy supplier that is willing to invest in meeting that demand. The literature study also found that niches can create transition enablers, these are listed in table 2.5. Validating these barriers and enablers and obtaining depth, detail and context to the case of a launching customer in the Dutch shipping energy transition will be a crucial part of the research approach.

The literature study found that there are multiple climate neutral energy carriers with accompanying niche technologies that are likely to be used in the future. The technology is currently not fully developed and there are barriers for their implementation. Over time some barriers will go away, while other might never disappear because of the limits and characteristics of the technology and energy carrier. Ammonia will for example always remain toxic and batteries will probably never have an energy density that is comparable with diesel. The theoretical framework shortly discussed batteries, hydrogen, methanol and ammonia and compared them on some key characteristics such as energy density, storage volume, total costs of ownership and Technology readiness level, for example in figure 2.8.
The development trajectory of these energy carriers will play an important role in the transition. Choosing one or multiple energy carriers to do pilot projects with will have a large impact on which transition enablers are created and the resulting environmental benefits. It is therefore important to know which energy carriers are considered by the sector and on which criteria they are assessed. The literature has already provided some knowledge, but it would be valuable to know what the actors in the Dutch shipping cluster think about this subject.

### The transition

The developments on the three levels will shape the transition pathway and timeline of the Dutch shipping cluster. When climate neutral sailing fully develops over time the adoption of the climate neutral 'ways of doing' will start to become feasible for more and more organizations. The risks and investment costs of a transition will have gone down and the operational feasibility of alternative energy carriers has gone up. Pilot projects by launching customers are expected to play a crucial role in this. However, the lock-in mechanisms of the old cluster and individual sub-regimes will still exist and a transition might still be economically unattractive when only niches develop. Landscape pressure is therefore needed to change the stability of the old cluster and improve the financial feasibility of a transition with a new regulatory framework. These will be difficult to implement in at a global level, because of the complex governance structure. However, it is expected that for a specific sub-regime in the Netherlands such a regulatory framework could be implemented a lot easier. If the transition feasibility of such a sub-regime is also relatively high it is the perfect place to start the transition. Pressure from the landscape and developments from the niche can reorient the development trajectory of regime actors towards the adoption of climate neutral 'ways of doing'. Regulations and policies can be set that specifically target a sub-regime for which the energy transition has become feasible. When more and more regime actors join a climate neutral sub-regime the stability and price and performance dimensions can be improved. The Rijksrederij is plans to be a launching customer in multiple niches, due to their diverse fleet, and is also in close contact with governing actors that can implement new regulations. Furthermore, with their fleet of over a hundred vessels than can start a serious demand for climate neutral 'ways of doing'. They are also a noncommercial organization with funding from the government. It is thus expected that the Rijksrederij can provide many transition enablers that will lead to large environmental benefits, if they reach their transition targets.

#### Focus of the research

The framework is based on the current understanding of the Dutch shipping energy transition. Further explorative research is needed to identify and verify all the transition barriers in the Dutch shipping transition and the transition enablers and resulting environmental benefits that can be created by launching customer, such as the Rijksrederij. The following step is to deepen the understanding of these topic and provide detail and context. Thereby the focus will lay on pilot projects, since this is expected to be a key step in the development of niches and is already being planned by the Rijksrederij. This pilot projects research will focus on the development trajectory, management and resulting transition enablers.

## 3.2 Semi-structured interviews

The first step in answering the research question is to identify the barriers that are currently slowing down the transition. This is followed by a discussion of which transition enablers would take these barriers away. The last step is identifying which of these transition enablers can be created by a launching customer and specifically a pilot project.

A qualitative approach is chosen since the aim is identification and understanding of topics that are not easily quantified. The scope thereby starts with a broad perspective, to ensure that all possible significant elements are included. As the research progresses the scope converges to the elements that are important for answering the research question, such as transition enablers created by launching customers during pilot projects. This is visualised in figure 1.5. Semi-structured interviews with a limited number of experts will be conducted for which the theoretical and transition framework form the basis. These interviews can verify, adjust and add to the framework discussed in the previous section by providing in-depth knowledge on the Dutch shipping energy transition.

The theoretical framework already provided an overview of the elements that play a role in the shipping energy transition and led to the expected pathway of the transition. This has, together with insights and reasoning of the author, led to the framework for further research which includes the transition barriers for the different levels in tables 2.2, 2.4 and 2.3. The literature study could not limit the scope to the Dutch shipping sector, since there was not enough literature available. A detailed description of the Dutch shipping energy transition barriers, enablers and pilot projects is currently missing in literature, this thesis can change that.

Semi-structured interviews with experts can be used to explore subjects in depth since they are not limited by a certain set of questions. The interviewer will have some questions to structure the interview and ensure that all the topics are touched, but has room to start a discussion or hear out the interviewee on a specific topic. These type of interviews can therefore be used to verify a transition framework (Bergsma, 2019). This method was also used by (Mander, 2017) for a MLP analysis of slow steaming and wind propulsion where it was effective in exploring the implications of the two sustainable measures. The interviews will be transcribed verbatim and analyzed qualitatively using Atlas-ti to find the themes and elements that emerge. A detailed description of how Atlas-ti was used in this thesis can be found in appendix I.

### Structure for the interview

The structure for the interviews will ensure that all topics are touched. The topics will be transition barriers, transition enablers and specifically transition enablers resulting from pilot projects and launching customers. Interviewees were also asked about which climate neutral energy carriers could be used in the future, to get an insight into this discussion. Actors from the different MLP levels will be asked to elaborate more on the specific conditions for their level. Verification was done by asking actors if they think a certain element from the framework plays a role, if it was not already mentioned. The interviewee thereby avoids being suggestive.

1. Which type of organization (shipbuilder, shipowner, etc.) do you represent and what is your function in this organization?

   Introduce the Dutch shipping cluster to ensure the interviewee understands what is meant by the term: the Dutch shipping cluster consists of ports, inland shipping, maritime shipping, shipyards, shipping suppliers, shipping services, yacht building, fisheries, navy, offshore, inland water construction.

2. What are in your opinion the barriers that slow down the energy transition of this shipping cluster, from fossil fuels to climate neutral energy carriers?

3. When a barrier from table 2.2 (regime barriers) is not mentioned ask if that barrier could perhaps also play a significant role.

   Statement 1: both developments in climate neutral sailing as new regulations are necessary to make a transition possible for the Dutch shipping cluster.

   Statement 2: further developments of climate neutral sailing are needed to make the operation feasible and financially more attractive. Regulations are needed to enable climate neutral sailing to out compete carbon-based sailing, by making it financially more attractive.

4. What is your opinion on these statements?

5. What are in your opinion the barriers that slow down the development of climate neutral sailing?

6. When a barrier from table 2.4 (niche barriers) is not mentioned ask if that barrier could perhaps also play a significant role.

7. What are the options for legislation that will stimulate the energy transition?

8. What are in your opinion the barriers that slow down the implementation of new legislation that stimulates climate neutral sailing or discourages the use of fossil fuels?

9. When a barrier from table 2.3 (landscape barriers) is not mentioned ask if that barrier could perhaps also play a significant role.

10. Considering the barriers for the cluster, climate neutral development and legislation, what could be the contribution of pilot projects and launching customership that enables others to make a transition and shorten the transition timeline?

11. When a barrier from table 2.5 (niche benefits) is not mentioned ask if that perhaps could also play a role.

12. Which climate neutral energy carriers could be used in the future and on which criteria would you judge the candidates? Only ask this if this has not yet been discussed.

13. Do you have anything to add on the discussed topics?

### Transition barriers

The answers on questions 2 and 3 can be used to verify and deepen the knowledge on transition barriers. It is expected that the barriers differ per sub-regime but that there are also strong connections between sub-regimes, the knowledge from experts can further develop this concept. By using table 2.2 as a reference the barriers found in literature can be verified. By asking if it 'might play a significant role' one avoids that the interviewer is suggestive and places words in the mouths of the interviewees. The knowledge on transition barriers can be used to answer the first sub-question

#### Transition enablers

Questions 4, 5, 6, 7, 8 and 12 can be used to deepen the understanding of the required transition enablers and resulting transition pathway. It is expected that the interviewees have different opinions since there are still many uncertainties, for example the choice of energy carrier appears to be unclear. An overview of the required developments can thus lead to an interesting discussion of the transition enablers and a verification of the knowledge from the framework. This knowledge can be used to answer the second sub-question and created an understanding of the role launching customers play in the total transition process.

#### Pilot projects

Questions 5, 6, 10 and 11 can be used to verify and deepen the knowledge on pilot projects. The barriers for the development of climate neutral sailing can be used to give insights into the development trajectory of pilots project. This can be visualized into an overview of the required interdependent developments. For example, the engineering, building and certification of the pilot vessel. The development trajectory can be linked to the transition enablers that can be created by pilot projects. The impact of the pilots can be optimized by sticking to management guidelines, such as SNM that was described in section 2.2. The knowledge from interviewees can be used to develop guideline specifically for the strategic management of shipping pilot projects and present an overview of the resulting transition enablers. This knowledge can be used to analyse pilot projects, answer the third sub-question and the answer the main research question.

#### The interviewees that are required for a holistic overview

Table 3.1 lists the actors that are required for this research approach, categorized by the levels from the MLP and if they are or are not related to Rijksrederij. This list is based on the aim of the semi-structured interviews and the wide range of actors that the energy transition depends on. It should be noted that actors, such as a shipbuilder or port, can be active in both the niche and the regime level. This could limit the amount of interviews that is needed to obtain a holistic overview. Furthermore, shipyard will for example also have knowledge on engineering, classification, shipping suppliers and shipowners demands which further limits the amount of required interviewees for a holistic overview.

| | **Rijksrederij related** | **Reference actors** |
|---|---|---|
| **Landscape Actors** | Dutch ministry of Infrastructure and Water Management<br>Dutch ministry of Economic affairs | Dutch ministry of Infrastructure and Water Management<br>Dutch ministry of Economic affairs |
| **Dutch shipping Cluster Actors** | Rijksrederij Shipbuilder<br>Rijksrederij Management | Shipbuilders<br>Ports<br>Ship owners<br>Naval architects<br>Branch organizations |
| **Dutch Climate Neutral Niche Development Actors** | Pilot Project Shipbuilder<br>Pilot Project Management | Project leaders<br>Innovators/Researchers<br>Shipbuilders<br>Ship owners<br>Ports |

**Table 3.1:** The actors that will be needed for this research approach, categorized by the levels from the MLP and if they are or are not related to Rijksrederij.

## 3.3 Case study methods

Case studies can be used to provide depth, detail and context to the knowledge and theories that were obtained during the semi-structured interviews (Given, 2008). Case studies of pilot projects can provide data with which it might be possible to obtain some level of quantification of the transition enablers that can be created by launching customers and their pilot projects. This can give further insights in the pilot projects development trajectories and management that will be used to substantiate the answers of the third sub-question and main research question.

It will also be used to reflect on the gained knowledge on transition barriers and enablers. For example, by assessing which barriers are indeed less pronounced for these pilots, which barriers the pilots still encounter and are which barriers are targeted by transition enablers.

Semi-structured interviews with project leaders can again serve as an effective method for obtaining in-depth knowledge. These will be based on the theory on pilot development trajectories, strategic management and transition enablers from the initial interviews with industry experts. New methods will be needed for the quantification of transition enablers, these will be introduced in this section.

### 3.3.1 Technology readiness level and associated risk

The Technology Readiness Level (TRL) assessment is a method which uses a scale from 1 to 9 to rate the maturity of the technology. TRL originates from the American National Aeronautics and Space Administration (NASA) and has grown out, via various mutations, to an official innovation policy tool of the European Union (Héder, 2017). The 9 levels of technology readiness that the EU used for its 2020 horizon project are listed below (Héder, 2017).

- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

These levels will give a common understanding of the state of development of the technology to people who are not experts in the field. The state of development can be linked to the risks, the lower the TRL the higher the risk that the technology will not perform in the actual operational environment. A low TRL means that there might be a long and costly development trajectory before a technology can be implemented. A shipowner might therefore not be interested in technologies with a low TRL. A TRL step resulting from a pilot project can make the technology interesting for many actors, and thereby enable a transition. This method can thus be used to assess the level of technological development that is being achieved by a project. The TRL is determined with a Technology Readiness Assessment, this is done by checking which level fits best to current state. A case study on pilot projects can give insights into the TRL improvements that could be achieved by Rijksrederij pilots.

An important note concerning TRL is that it only assesses if the technology in question is proven in its operational environment. A technology can be TRL level 9 without anyone being interested to use it because there is no market readiness (Héder, 2017). When the costs are too high or the infrastructure and regulations are not aligned with the new technology a transition can still be infeasible. Another note concerning TRL is that shipping technologies are often adopted from other sectors in which they have already reached TRL 9. Such a technology is then considered TRL 5 for shipping technology and only needs to be adapted for shipping purposes, when it is demonstrated to have a reliable and adequate performance during vessel operations it can be considered TRL 9. The shipping industry will thus not need to invent a battery, hydrogen fuel cell or electric engine but adapt and implement the technology that is developed outside the sector.

Other indexes that were also considered are the Integration Readiness Level (IRL) and the System Readiness Level (SRL) (Sauser et al., 2006). The IRL assesses the readiness to integrate one system into another. The SRL combines the IRL and multiple TRLs to assesses the maturity of multiple technologies that are forming a system together. The shipping energy transition does not require many new technologies to work together in a complex system. One capable engine or energy converter with accompanying climate neutral energy carrier is at the technological side enough for a transition. Since both the IRL and SRL are focused on integrating multiple new technology they are used as a method in this study.

### 3.3.2 Full energy transition marginal abatement cost

For the assessment of the financial feasibility of a transition the costs of the business as usual fossil fuel based operations has to be compared with climate neutral sailing. The Marginal Abatement Cost (MAC) can be used to assess the costs of reducing emissions. The Rijksrederij wants to make a full transition towards a climate neutral sailing which requires a new energy carrier. Energy saving measures can help, because they reduce the amount of energy that has to be stored on board, but this will only reduce a fraction of the emissions. This study therefore focuses on a full energy transition and therefore uses the MAC to assess full transitions and not energy efficiency measures. The MAC calculates the costs for reducing emissions per tonne CO2 equivalent as a result of an energy transition. The MAC for a vessel can be calculated by the costs of climate neutral sailing minus the cost of the business as usual case divided by the tonnes of reduced CO2 equivalent emissions. The MAC can be negative, this is the case when the climate neutral option is cheaper than the business as usual fossil fuel one.

The development of the MAC is an important factor in the energy transition. A negative MAC will stimulate the transition since it creates a clear financial incentive for every shipowner to make a transition. When the MAC is to high the interest in the transition will probably be limited since the willingness to pay from commercial actors is limited. Launching customers can reduce the MAC for other actors by their developments, which is a transition enabler since it reduces transition barriers.

#### Calculations

Based on the definition of the MAC a simple formula can be created to calculate the costs of a transition per ton CO2 equivalent not emitted for a specific vessel. These formulas are presented in equation 1 to 3 below and are based on the costs of overcoming the barriers for the climate neutral niche 2.4. The formulas consist of the following elements: CAPEX, OPEX and GHG reduction for a vessel type that runs on fossil fuels, the first climate neutral vessel and a follow-up. The MAC can be calculated by taking the difference between the CAPEX and OPEX of climate neutral sailing and fossil fuel sailing and dividing this by the GHG reduction. The MAC reduction can then be calculated by calculating the difference between the MAC of the first climate neutral vessel and the follow-up, which illustrates the cost reduction that has been created by the launching customer. Such a cost reduction enables other to make the transition. The ratio between the additional CAPEX and additional OPEX of climate neutral sailing gives an indication of the origin of the extra costs.

The CAPEX calculates the yearly depreciation of a vessel. These extra costs are expected to go down as a result of technological development, engineering experience, design codes in regulation and production scale-up of the required components. The CAPEX includes the costs for obtaining all the required licenses and certificates and any costs for covering possible extra risks. With new and innovative projects, such as pilot projects, there is always a chance for failures as a result of unforeseen or uncertain elements. Other non-recurring costs such as crew education or assembling a project group also fall under the CAPEX.

The delta OPEX calculates the yearly operational expenses of a vessel. The difference between a climate neutral OPEX and a fossil fuel one will probably originate from the different price of the energy carriers. The development of these prices will thus impact the OPEX and thereby impact the MAC. Large investments in for example energy carrier production or bunker infrastructure will result in a lower climate neutral OPEX. Note that energy efficiency of the used technologies also plays a role, a fuel cell might for example be more energy efficient than a combustion engine.

$$MAC = \frac{CAPEX_{\text{Climate neutral}} - CAPEX_{\text{Fossil fuel}} + OPEX_{\text{Climate neutral}} - OPEX_{\text{Fossil fuel}}}{\text{GHG reduction}} \tag{3.1}$$

$$\Delta MAC = 1 - \frac{MAC_{\text{Follow-up}}}{MAC_{\text{Pilot vessel}}} \tag{3.2}$$

$$RATIO_{\Delta \text{ CAPEX}/\Delta\text{OPEX}} = \frac{CAPEX_{\text{Climate neutral}} - CAPEX_{\text{Fossil fuel}}}{OPEX_{\text{Climate neutral}} - OPEX_{\text{Fossil fuel}}} \tag{3.3}$$

### MAC development

A sketch of three development scenarios for the MAC for a certain vessel type over time is visualized in figure 3.2. The CAPEX and OPEX of climate neutral sailing are currently high in relation to staying in the business as usual case and there will also be significant transition costs since there are no clear climate neutral 'rules of the game'. It is expected that a pilot project by a launching customer can already significantly reduce the MAC in the coming years, since it would stimulate all sorts of developments. When the project has follow-ups, the MAC can be reduced further over time due to economies of scale. The MAC reduces further as the adoption progresses from innovators to early adopter to early majority, which makes the 'ways of doing' increasingly accepted. However, it is not likely that the MAC becomes negative without a regulatory framework, since fossil fuels are cheap and have an enormous advantage at the moment. It is expected that for this vessel type in figure 3.2 the MAC can only be brought below zero when a certain regulatory framework is adopted that subsidizes climate neutral sailing or puts extra costs on GHG emissions. This scenario is also visualized in figure 3.2, together with a scenario without launching customers and a regulatory framework.

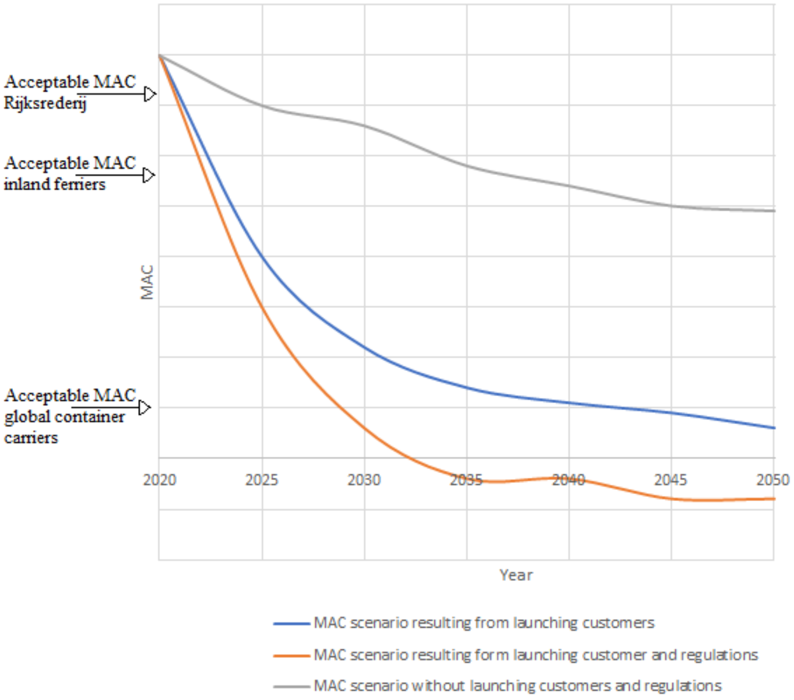


**Figure 3.2:** Sketch of what the reduction of Marginal abatement costs as a result of a launching customer might look like in comparison with no launching customership. It is expected that launching customers in combination with a regulatory framework could make the MAC negative

### The acceptable MAC

A reduction in MAC will improve the market readiness but the effect can be limited for a certain ship type, operation, operational area or organization. Organizations for which the lock-in mechanisms that are listed in table 2.2 and table 2.4 are less pronounced might be able and willing to pay a certain price per tonne of GHG not emitted. This further explains and now also enables one to quantify that for some organizations the climate neutral business case will be more feasible than others. Not only is the MAC different but so is the MAC that is acceptable. This acceptable MAC is also visualized in the sketch in figure 3.2, for the same cases as table 2.1.

According to (Lloyd's register, 2017) 75% of international shipowners agree that a carbon price is needed in the sector, most of them would be willing to pay US50$ per tonne of CO2. This would thus be an acceptable MAC as long as everyone has to pay it. However, this requires action from regulators who experience their own barriers, which are listed in table 2.3.

The cost of not emitting carbon can be linked to the social cost of carbon emissions. This quantifies the impact on the environment and human health from emitting a tonne of CO2 equivalent at any given point in time. This cost can be used to quantify the direct environmental gains but also give insight into what an acceptable MAC is from a societal standpoint instead of a business standpoint. In (Ricke et al., 2018) multiple scenarios are assessed and a median social cost of carbon is estimated at US$417 per tonne of CO2 equivalent. This value is considerably higher than the US$50 dollars most international shipowners are willing to pay.

## 3.4 Research approach

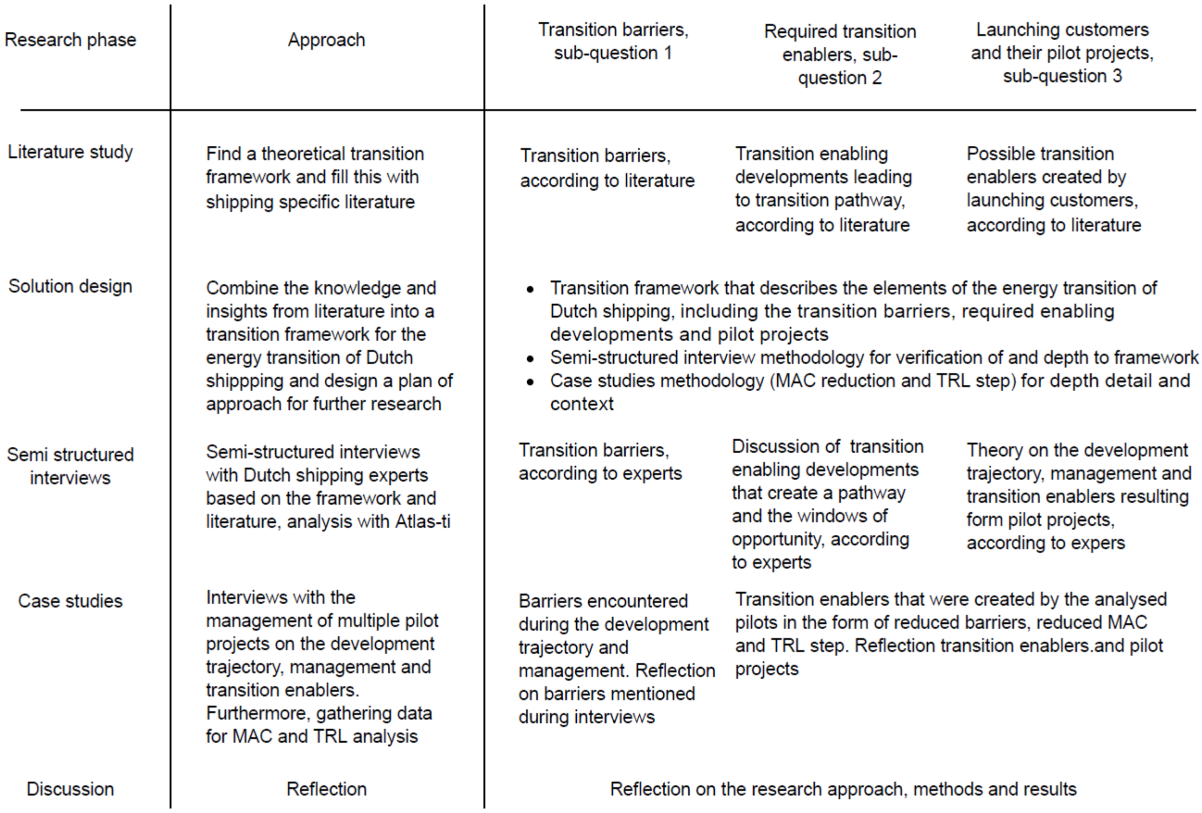
The research approach is visualized in matrix form in figure 3.3. The literature study in chapter 2 summarizes knowledge on transition barriers, required transition enablers and specifically launching customers and their pilot projects with a broad scope by using the MLP as theoretical framework. The solution design combines the knowledge and insights into an new transition framework for the energy transition of Dutch shipping and develops a methodology for semi-structured interviews and case studies. These semi-structured interviews provide more in-depth knowledge on Dutch transition barriers, required transition enabling developments and pilot projects in chapter 4, as described in section 3.2. More depth, detail and context is provided by the case studies in chapter 5 which includes an assessment of the change to MAC and TRL, as described in section 3.3. The scope broadens again in the discussion which reflects on the research approach, methods and results. These research phases include a reflection on how the newly obtained knowledge corresponds with previous findings and what this means for the case of the Rijksrederij. This approach is corresponding with the scope that was visualize in figure 1.5 but has more detail to explain the structure of the thesis.

### Validation and verification

The results of the literature study have been translated into the transition framework at the beginning of this chapter. The literature focuses mainly on the global shipping sector and not specifically on the Dutch shipping cluster. The framework has been made with some assumptions and new insights from the author that have not yet been verified, it is therefore possible that some parts are not fully accurate. Since this is the basis for further research it is vital to extensively verify and validate the framework and add any missing elements. This will be done by the semi-structured interviews with expert actors from the Dutch shipping cluster. Combining the knowledge from literature, own insights and over a dozen industry experts will yield a reliable, verified and holistic overview of the energy transition.

The semi-structured interviews themselves also need to be validated and verified. Verification of the answers is done by sending the transcript of the interview to the interviewee and ask if the information in the transcript is correct. The interviews of multiple experts are compared during the Atlas-ti analysis, this will show if the views of the experts are coherent and consistent or that there are irregularities. Only when all experts agree on something a reliable conclusion can be made, it will be mentioned when opinions among the experts differ.

The final verification and validation step will be made during the case studies of pilot projects. These will prove if the theory and knowledge that was developed matches the experience from actors in the field. This will be done by presenting the knowledge and theory to project leaders and asking for feedback. Furthermore, the data points provided by case studies can also be used to reflect on the results of the semi-structured interviews.



| Research phase | Approach | Transition barriers, sub-question 1 | Required transition enablers, sub-question 2 | Launching customers and their pilot projects, sub-question 3 |
|---|---|---|---|---|
| Literature study | Find a theoretical transition framework and fill this with shipping specific literature | Transition barriers, according to literature | Transition enabling developments leading to transition pathway, according to literature | Possible transition enablers created by launching customers, according to literature |
| Solution design | Combine the knowledge and insights from literature into a transition framework for the energy transition of Dutch shippping and design a plan of approach for further research | • Transition framework that describes the elements of the energy transition of Dutch shipping, including the transition barriers, required enabling developments and pilot projects<br>• Semi-structured interview methodology for verification of and depth to framework<br>• Case studies methodology (MAC reduction and TRL step) for depth detail and context | | |
| Semi structured interviews | Semi-structured interviews with Dutch shipping experts based on the framework and literature, analysis with Atlas-ti | Transition barriers, according to experts | Discussion of transition enabling developments that create a pathway and the windows of opportunity, according to experts | Theory on the development trajectory, management and transition enablers resulting form pilot projects, according to expers |
| Case studies | Interviews with the management of multiple pilot projects on the development trajectory, management and transition enablers. Furthermore, gathering data for MAC and TRL analysis | Barriers encountered during the development trajectory and management. Reflection on barriers mentioned during interviews | Transition enablers that were created by the analysed pilots in the form of reduced barriers, reduced MAC and TRL step. Reflection transition enablers.and pilot projects | |
| Discussion | Reflection | Reflection on the research approach, methods and results | | |

**Figure 3.3:** The plan of approach for the semi-structured interviews and the case studies

### Data management plan

Personal data is collected during the semi-structured interviews, such as email addresses, names video and audio data. Therefore, a watertight data management plan is made. Each interviewee will receive an information letter to inform them about the research, which data is being collected and inform them that the information that they provide will be used for scientific purposes and possible future publications. When the interviewee has read the information letter, they are asked to sign the informed consent form. With this form permission is given to use the information provided in the interview and the interviewee declares that they have understood the content of the information letter. The information letter and informed consent form can be found in appendix II and III. Note that although personal information is collected it does not concern particularly sensitive information, since it is concerning the energy transition which is not considered a particularly sensitive or personal subject.

The audio data will be transcribed verbatim, anonymized and saved in a database at the TU Delft. Only the research team, excluding members of the Rijksrederij, can access these files. This ensures that the information presented in this thesis and possible publications cannot be traced back to an interviewee. Furthermore, interviewees do not have to keep their relationship with the Rijksrederij in mind and can answer freely, since the Rijksrederij has no access to the interview data.

# Chapter 4

# Results of the Semi-structured Interviews

A total of 13 interviews with experts from multiple organizations have been conducted with the aim of verifying, adjusting and gaining insights in the transition framework that was discussed in section 3.1. The organizations that participated include the ministry of Infrastructure and Water Management, the ministry of Economic Affairs, shipyards, shipowners, an engineering firm, ports and branch organizations (for production and for shipowners). A variety of experts from different shipyards and shipowners were interviewed, since there are large differences between the larger ones that operate globally and the smaller ones that operate locally. Five of the interviewees have a professional relation with the Rijksrederij or had one in the past. Two interviewees are currently working at the Rijksrederij. This ensured a broad scope with the possibility to focus on the Rijksrederij.
The experts had a range of functions with different degrees of focus on sustainability. Some of the interviewees had a function that specifically focused on it, such as project leader for the energy transition and a representative for the environment and climate. Others had a function where sustainability plays an important part, such as lead naval architect, innovation director, principle research engineer, business strategist and fleet performance manager. Finally, there was also a group for whom sustainability was just one of the many topics on their agenda, such as directors and owners, a liaison officer and an operational manager.

Some of the key parts from section 3.1 where mentioned in the interviews for verification and structuring, as described in the section 3.2. This proved to be an adequate method, since most interviewees had knowledge about the different elements of a topic but did not bring up all of them on their own. The explorative set-up also proved effective to deal with the variety of topics and experts, since it gave the opportunity to discuss a topic in depth when the interviewee proved to be particularly knowledgeable. By combining the knowledge from different interviewees, a detailed and holistic description of the shipping energy transition and the value of leadership in this transition could be created. This was done by categorizing and then labelling the knowledge from the interview transcripts. This chapter will follow the structure of the interviews, as described in section 3.2.

This chapter will start with a detailed description of the transition barriers, which is followed by a discussion on the required transition enablers and windows of opportunity. Next are three sections that present theory on the development trajectory, management and resulting transition enablers of pilot projects. The final sections of this chapter reflects on the gained knowledge and the case of the Rijksrederij.

## 4.1 The barriers that slow down the energy transition of the Dutch shipping cluster

The transition barriers for the shipping cluster that were found in literature are listed in table 2.2. These barriers were also one of the main topics in the interviews, as described in the interview structure in section 3.2. The barriers that were mentioned and explained by the interviewees are discussed in detail in the following sections. A summary of these barriers can be found below. The socio-technical element, mentioning percentage and focus of actors per barrier can be found in table 4.1.
All barriers from table 2.2 are mentioned in the detailed description, but it was found that they can all be seen as part of the barriers mentioned below. Categorizing all the barriers under these six main ones creates some valuable structure in this complex situation. This is a direct result of studying, categorizing and labelling the interview transcripts.

**Interdependency**
The value chain in the Dutch shipping cluster is long and has many interdependent actors that all have to adapt, which creates inertia for the required radical change.

**Commercial infeasibility**
For a commercial company, the cost of a service must be lower than what the customer is willing to pay and the risks must be marginal. However, the investments and risks of a climate neutral service are too high for what customers are willing to pay, which makes a transition commercially infeasible.

**Uncertainty**
There is great uncertainty as to where, when and at what cost a certain vessel will be transitioning to a certain energy carrier and technology, which limits investments.

**Assets**
The lifetime, costs, low production quantity and need for proven reliability of the required vessels and infrastructure strengthens the lock-in.

**Regulations**
The stringent fossil fuel-based regulations and classification practices obstruct rather than stimulate the use of climate neutral energy carriers and technology.

**Mindset**
The actors are risk averse and focus on their own link in the chain, which makes their possibilities to contribute to the transition small.

| Transition barrier | Socio-technical element | Mentioned by Interviewees [%] | Focused on by |
|---|---|---|---|
| Interdependency | All | 100 | All said to be strongly dependent on others |
| Commercial infeasibility | Market and user practices | 77 | Shipowners, shipyards and branch organizations |
| Uncertainty | Technology, infrastructure and market and user practices | 100 | All said that there are major uncertainties |
| Assets | Technology and infrastructure | 92 | Engineers and branch organizations |
| Regulations | Regulations | 92 | Engineers, shipyards and branch organizations |
| Mindset | Mindset | 85 | Governmental actors and branch organizations |

**Table 4.1:** The socio-technical element, mentioning percentage and focus of actors per barrier

### Interdependency

In section 3.1.1 the cluster of shipping sub-regimes is discussed. This is characterized by the socio-technical elements: technology, infrastructure, mindset, market and user practices and regulations (Geels, 2012), which are strongly aligned within a sub-regime. The actors are dependent on this alignment for stable operation since it creates clear 'ways of doing' that can easily be followed, but this also creates a large inertia for change (Geels, 2002)). The interviews led to a better understanding of the alignment and interdependency between actors in the shipping cluster, which also supports the understanding of the other barriers.

The shipping cluster can be conceptualized as a chain of interdependent actors, each actor provides a crucial component to the cluster. When a shipowner wants to use a radically different technology it depends on other actors across the chain to align their socio-technical elements with this new technology. In figure 4.1 the chain of interdependent actors in the shipping cluster is illustrated from the perspective of a shipowner. The shipowner is the actor that makes the decision to order a new vessel and sets the requirements for the vessel. An engineering firm uses these requirements to design a vessel, in accordance with the regulations in the cluster. Many of the key components in the design are products from suppliers, such as the engine, propeller or a pump. These components are typically serial products which are designed and produced by a specialized company. The chain is dependent on these suppliers for new and innovative components, such as engines that run on climate neutral energy carriers.

A shipyard builds the casco and integrates all the components from suppliers into the vessel, according to the design of the engineers. Vessels are often custom built or small series, which means that engineering costs cannot be spread out over many vessels and there is always a risk of teething problems. This limits the funds for innovation, as was also mentioned by (Wijnolst and Wergeland, 2009). Note that one company can have multiple branches that are active in different parts of the chain. Engineering and building can for example be done by the same company and a shipowner can also be the customer of the service, such as the owner of a yacht who is also the customer for recreation.

Before a vessel can be taken in operation it has to receive a certificate, which is provided by a classification society. A vessel can easily receive a certificate when it is build in accordance with pre-set design codes, which are developed for common technologies such as diesel engines. However, these pre-set codes might not yet exist for new technologies. In that case the safety of the ship must be proven, which requires an extensive safety study.

During its operational life the shipowner, customers, ports and energy suppliers are dependent on each other's services. Vessels can have many purposes in which they often deliver a service to a customer such as transport, dredging or fishing. To deliver this service, the shipowner and customer are depending on the infrastructure of ports and the fuel from energy suppliers. The technical and economical lifespan of a vessel will typically be 30 years, with extremes up to 50 years. During this lifetime the vessel will need maintenance and perhaps upgrades which can again be provided by the production part of the cluster. Financial institutions support actors across the chain, by granting loans for their investments and insuring their assets and operations.

The cluster also has a couple knowledge institutes and branch organizations, which are not a link in the chain but are active in both the production and operation part of the cluster. The branch organizations represent a part of the cluster, defend their interest and support their operations. Knowledge institutes stimulate and support the sector with their research. Regulatory bodies have a lot of influence on the entire cluster by adopting regulations, but are also not a link in the chain.

### Commercial infeasibility

The actors from the chain of figure 4.1 are in general commercial businesses, therefore the aim of their work is to make a profit. The actors will only partake in a project or if there is a business case, a prospect of future gains with limited risks. Commercial shipowners will only order a climate neutral vessel if they believe that they can win back the investment over time, but they do not. A commercial bank only grants a loan for a climate neutral vessel when they believe that the shipowner will be able to pay off the loan in the future, but they are hesitant. A commercial shipyard only builds a climate neutral vessel when it is ordered and payed for, but nobody orders one. There are some exceptions of noncommercial actors in the shipowner and customer category, these will be discussed later in section 4.3.

Most actors experience fierce competition, this puts pressure on the profit margins and makes actors cautious with investments. Many shipowners and shipyards have margins close to zero, or sometimes even below zero. Since the arrival of Covid-19 these margins are under even more pressure. One interviewee said: "Companies are constantly trying to survive which leaves little time and energy to look at other options". The margins have been low for a long time. As a result, many companies have little

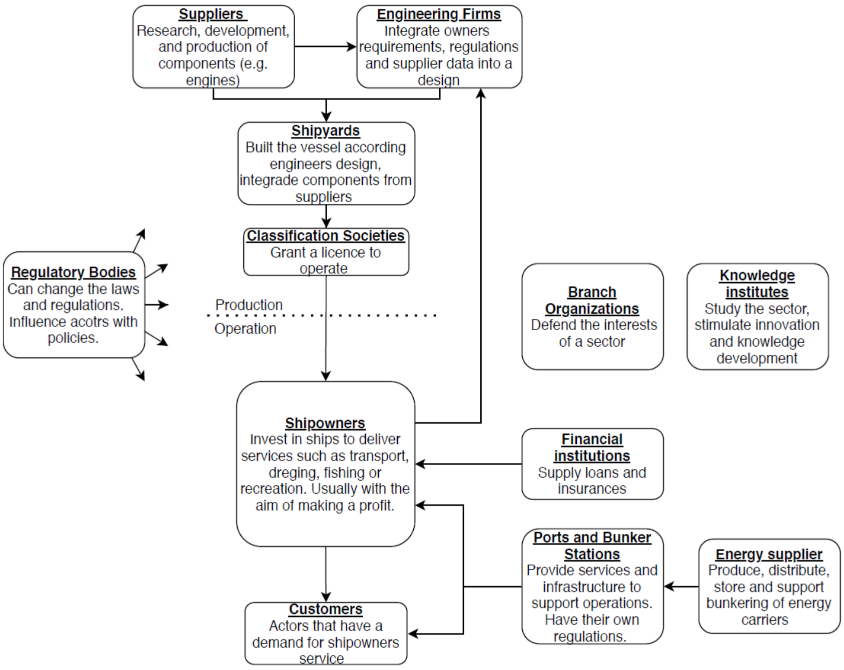


**Figure 4.1:** The value chain of interdependent actors in the shipping cluster

cash to invest in innovative experiments.

Shipowners want to be certain that there is a long-term business case and reliable operation, since a vessel is a very enduring asset that needs to be profitable for a long time to get a return on the investment. The combinations of small margins with high capital investments means that a mistake at both the production and operation part of the cluster can have large consequences. An interviewee said: "A shipyard can have a margin of a few percent on a turnover of many millions. They can go bankrupt when they have a bad project and the risks are always high since new build projects are often custom build".

In the current cluster sailing with climate neutral technology requires large investments and leads to higher operational costs and risks, while the customers are not willing to pay more for the service, according to interviewees. Instead of a commercial incentive there is a commercial disincentive. The fast majority of customers aim to acquire the service they need for the lowest price. These customers are often also commercial businesses that try to limit their expenses. They cannot translate the extra costs of a sustainable service to their customers or are not interested in trying to. Furthermore, customers buy their services at agents in some sub-regimes, this middleman makes it difficult to negotiate directly with the shipowner about sustainability. Note that, the extra costs would often only lead to marginal price increases for their business case, since shipping is relatively cheap.

The interviewees do not expect that this unwillingness to pay for climate neutral services will significantly change soon. When the climate neutral business case of a shipowner leads to higher costs and less reliability which is not compensated by an increased income it is not feasible for a commercial shipowner. An interviewee said the following about this topic: "It will only cost a ship-owner money. I think he will go bankrupt". This corresponds with the barrier that actors are, and can only be interested in commercial gain because of tough market competition which was based on the work of (Psarros and Mestl, 2015).

The lack of interest in climate neutral sailing from customers slows down developments further down the chain. There will be no demand for climate neutral vessels when there is no willingness from customers to pay more for climate neutral services. This means that there is no business case to further develop and prove technology or to invest in infrastructure and climate neutral energy carriers. A commercial partner therefore experiences an unbalance between the required investment, possible return on investment and risks for climate neutral sailing.

### Uncertainty

It is difficult to get an overview of the current and future performance, price, availability of technology, infrastructure and energy carriers. The future support from regulatory bodies and interest from regime actors is also unknown. These are all significant elements that influence one's choice to make a transition, which makes this choice complex and risky. The case of climate neutral energy carriers is a particularly uncertain, which has large consequences. There is simply no climate neutral alternative to fossil fuels that will have the same energy density, availability, ease of storage, ease of bunkering and low price. Therefore, the question of what the fuel of the future will be is not easy to answer, especially since different ships will have different demands. It is widely believed that multiple energy carriers will be used in the future, there is no 'silver bullet' or one size fits all solution.

There are many criteria that need to be considered when selecting a climate neutral energy carrier for your vessel. Some important ones are the amount of space on board of your vessel, installation costs (capital expenditures), costs of the energy carrier (operational expenditures), (green) availability and obviously the energy requirement of your vessel. Knowledge about all these properties is needed in order to pick the right one. Safety is also an important criterion but the interviewed engineers are not too concerned, since ships are closed environments with trained professionals that can be educated.

With the choice for an energy carrier comes the choice for matching technology. There are typically many concerns about the performance of a technology when this has not been fully developed or even tested in practice, as is the case with most of the climate neutral propulsion options, according to interviewees. Staying informed about what is currently possible requires actors to monitor all kinds of sources such as websites, magazines, papers and expert opinions. Interviewees say that it is difficult for actors in the cluster to stay up to date with all the developments, it is therefore believed that there is a lack of knowledge among many actors regarding these significant subjects. This corresponds with the barrier that actors have a lack of knowledge, competence and awareness with regard to sustainable shipping, which was based on (Dewan et al., 2018). This will increase the sense of uncertainty.

The interviewees also said that it is uncertain when availability of energy carriers will be sufficient in an operational area and against which price, some expect that the costs of a climate neutral fuel will double the costs of a service. There are business cases where fuel costs are up to 70% of a shipowner's total costs, such as deep sea shipping. A shipowner must be certain that his customers are willing to pay the extra costs, otherwise there is no balance between investment, risks and return on investment. When the uncertainty is so high actors are reluctant to take action and start solving the availability problems. The uncertainty about the future climate neutral energy carriers is likely to lead to non-linearity which creates the hype-disappointment cycles that are discussed by (Geels, 2012) and visualized in figure 2.3. This will also make it difficult to govern the transitions, as was discussed in section 2.2 based on (Newig et al., 2007).

The uncertainty can be seen as a result of niches that have not fully developed, since the expectations and visions are not articulated (Kemp et al., 1998). Furthermore, learning processes have not stabilized in a dominant design, powerful actors have not yet made the transition and climate neutral niches do not amount to 5% of the market share, which are criteria for a fully developed niche (Geels and Schot, 2007). However, uncertainty also comes from landscape developments and regime actors since these also influence the energy carrier selection criteria that have been discussed above.

### Assets

A shipowner requires new technology, infrastructure and the supply of a climate neutral energy carrier to deliver a climate neutral service. When these are not available, they cannot deliver the service and thus not make a transition. On the other side, technology suppliers, ports and energy suppliers need to be certain of a demand from shipowners before they make the large investments that are needed to develop and produce their assets. Interviewees call this a chicken and the egg problem, since it is a discussion of what must come first. Parties are dependent on each other to make large start-up costs before they can operate. These will not be easily made, since actors want to be certain of a return on this investment over the decade long lifetime of the assets. This corresponds with the theory presented by (Pettit et al., 2018)) that technologies are hypothesized to be 'strongly embedded' when they require large capital investments for technology and associated infrastructure.

Technology should not only be available but also proven to be reliable in an operational environment, according to shipowners. They prefer 'of the shelf' products since these are fully developed, robust and wide availability of spares and services. This is important since many vessels operate far from home and endure rough conditions. Furthermore, components are often difficult to reach and replace. If the propulsion of a seagoing container carrier fails, the vessel suddenly becomes a useless asset of tens of millions of euros, which will be costly to retrieve and repair. When this happens in the middle of a storm the ship and crew can even go down. On the other side, for a small shipowner, such as a family company with only one inland vessel, a new ship is a very large investment for which it is crucial to minimize the risks. This makes actors risk averse when ordering a new vessel. Since most vessels are custom built there is already risk that there are teething problems, most owners are not interested to add to this risk by installing unproven technology. This makes it difficult for suppliers to develop and prove their technology for climate neutral sailing, since it is so radically different from the current technology. It would require demonstrator projects, which are expensive given the costs of vessels. An interviewee said about this technology: ”unknown means unloved”. This corresponds well with the barrier that that there is a strong status quo in vessel design, since this ensures reliability (Gilbert et al., 2014) (Wijnolst and Wergeland, 2009) and the study of Lloyds (Lloyd’s register, 2017) that found that shipowners value reliability and scalability of a climate neutral alternative as more important than costs. Climate neutral technology will thus be a particularly difficult chicken and the egg problem since it must be proven, availability is not enough.

### Regulations

Another factor that slows down the transition is the lack of regulations that support the use of climate neutral energy carriers in the current cluster. There are for example no IGF codes for the use of most climate neutral energy carriers. These codes are standard rules and regulations that apply to the design of a certain vessels and technologies. The production part of the clusters is certain that they will obtain a certificate when the build the vessel in accordance with these codes. Without any codes it becomes more complex and uncertain, another pathway towards a certificate must be found. The design and certification of a climate neutral vessel will therefore be more expensive and take longer, since it must be proven that the new technologies are safe, which requires extensive studies. The rules and regulations for transport, storage and bunkering are also not aligned with climate neutral sailing and are often unnecessary stringent. An interviewee said that port rules for climate neutral energy carriers are based on the transport but not on the use of these fuels. These rules can make it impossible to operate on climate neutral energy carriers. Changing these regulations will only happen in response to a demand for climate neutral operations. At the moment there is no demand for climate neutral operations in the port and they are not certain how to adapt the rules to make them support safe climate neutral sailing, so they wait.

Some interviewees also mentioned that it is unfair that actors do not pay a price for their pollution which creates an unfair advantage for fossil fuels. If all shipowners had to pay for their pollution, such as CO2 emissions, a fossil fuel powered services becomes more expensive making climate neutrally powered services more attractive. This is seen as a flaw in the current regulatory framework. The interviewees are therefore open for, or even in favor of, a carbon tax, as long as the proceeds are used to stimulate the transition. The extra costs will be carried by the customer and the proceeds can be used to finance the costs of the transition.

### Mindset

The interviewees feel that there is an increasing pressure on the sector to become more sustainable but do not always feel responsibly to take radical action. Many interviewees have the idea that they lack the resources to make significant changes and that it is a problem across the chain, while they are only responsible for one link in this chain. The customers that are not willing to pay for climate neutral services are seen as the most significant problem in this chain, together with regulators. They feel that as long as there are no business cases for climate neutral sailing, or large investments to get over the chicken and the egg problems and get rid of all the uncertainty, there is little they can do. An interview said: ”I think that these investments are a job for the government, since they can fund it with public money”. Businesses are not large enough to fund the large development projects that are needed, since these projects are not expected to yield a return on investment in the form of money. They will yield valuable development of climate neutral sailing from which the entire society benefits; therefore, it is logical to fund it with public money, according to some interviewees.

Many actors see themselves as just one link in the chain, which corresponds with the barrier by (Mander, 2017) that actors are inward focused. However, the interviewees did not agree with the statement that they are not interested to make a contribution to climate change or are not interested in change in general, which was also mentioned in (Mander, 2017). The significance of reliability and the poor financial conditions means that actors are forced to be conservative to avoid endangering the future of their business. It is often said that shipping organizations are conservative, and that also appears to be the case, but the root of this conservatism is not genetic but rather a result of the difficult market conditions and significance of reliability. When organizations would have margins of 20-30% and could carry high risks they would be happy to design and operate the most innovative vessels.

## 4.2 Discussion of transition enabling developments

When all the possible transition barriers for the cluster had been discussed the interviews moved on to transition enablers, as described in section 3.2. The topics transition pathway, climate neutral niche development, regulatory changes and the selection climate neutral energy carriers were originally thought of as separate topics, as can be found in the questions section 3.2. During the processing of the interviews, the insight came that these are all transition enabling developments that can be divided into four categories: establishing and developing niches, increasing pressure and support from the landscape, reorienting the regime and the articulation of visions on climate neutral energy carriers. Which is corresponding with the transformation pathway as described by (Geels and Schot, 2007), with the addition of the enabling process of the articulations of visions on climate neutral energy carriers. The knowledge that interviewees provided on these four transition enabling developments will be provided below.

### Establishing and developing niches

Niches will need to be established since they provide a space were learning processes can converge in a stable design, which can then be adopted by regime actors (Geels and Schot, 2007). New engine and storage technology will be needed for the new energy carriers, or existing technology needs to be adapted for shipping purposes, since they are currently not fully developed. The required technology can be available for any of the discussed energy carriers within a few years, according to some interviewees, if they are not already available. Together they should be able to power the wide variety of ship types. The production part of the cluster is therefore not concerned about the technical aspect of the transition, even though the knowledge gap appears to be quite large. The challenge will be to prove the technology and make the designs adaptive to deal with the uncertainty. This means that shipowners can adapt their vessels to the developments that might occur during the lifetime of the vessel.

Reliable and affordable technology will come after a growing demand creates a scale up, according to interviewees. This demand growth will only come after technologies have been proven, demonstrator projects are therefore crucial. Suppliers are particularly interested in pilot projects since it gives them an opportunity to test their product and prove it to potential customers. Reliability of their product is important since they have to give out warranties and want to maintain a reliable image. Furthermore, it will give actors across the chain the chance to gain experience with the new technology, without a demonstrator this is difficult which limits developments.

Since reliability is such an important issue, some shipowners are considering dual fuel engines or dual engine installations to be able to operate with both climate neutral energy carriers and fossil fuels. It is expected that it will take some time before climate neutral energy carriers are available everywhere, which could hurt the operations of shipowners. There are also expectations that the new technologies will be less reliable in the beginning, which would also hurt the shipowner. Having dual fuel engines will tackle the problem of availability. A dual engine installation will tackle both availability and reliability problems, since many of the larger vessel are required to have multiple engines for redundancy this could significantly limit the risks while at the same time limiting the extra installation costs. It will also stimulate the demand for both climate neutral energy carriers and technology, which will not happen if everyone keeps waiting for perfect availability and proven technology.

Considering the long lifetime of vessels, a retrofit of the propulsion system might be desired in the future, in many cases this will be technically or commercially infeasible. Installing a new propulsion system is technically complex, an interviewee called it an open-heart surgery. Especially when the new system is larger or heavier than the original. Such complex operations will be a large investment that will again

only be made if the owner has confidence that he will win that investment back. This will only happen if the retrofitted vessel makes significantly more money or if there are subsidies.
It is thus expected that multiple niches will be established, based on a certain energy carrier but also on a specific technology or retrofit specialization. Dual fuel and dual engine designs can stimulate these niches by providing a solution for limited reliability and energy carrier availability. It is also expected that adaptability of a propulsion system will be required in the future, to deal with the uncertainties. Possibilities for establishing niches will be further discussed in the section 4.3 on the windows of opportunity. Section 4.4 on pilot projects will provide more depth into the trajectory, management and resulting transition enablers of establishing niches.

Interviewees say that the production and bunker infrastructure of climate neutral energy carriers must develop tremendously before the entire sector can be supplied. All climate neutral energy carriers are already produced but not in large enough quantities and not always in a climate neutral process. Since energy suppliers are also commercial organizations they are not likely to invest the billions of dollars that are needed to change this as long as the demand is not picking up, since they also see the uncertainties in the transition path, as was described in section 4.1. A demand growth can be stimulated by niches that gain momentum and grow. This requires that visions must become increasingly accepted, the learning processes converge into a dominant design and the social networks expand (Geels, 2012).
A growing demand for climate neutral energy carriers will stimulate suppliers to expand their production but the supply will probably lag behind the demand, since it is reactive and expanding the climate neutral production probably takes a couple years. Therefore, early adopters can be forced to sail on an energy carrier that is not truly climate neutral. However, it is obviously far better for the environment to sail the first couple of years on 'grey' hydrogen before switching to green than sailing the entire lifetime on fossil fuels, or relying on an expensive retrofit. It can however pose problems for the business case, since it will be even more difficult to translate the extra value of sailing on grey hydrogen to your customers than green hydrogen. When the public sees this phase as green washing it will hurt the image of the parties involved. However, the alternative is that actors wait until they are certain that green energy carriers are always available, which is likely to slow down the energy transition tremendously. Dealing with this situation will be a challenge for growing niches.
Interviewees say that multiple ports are developing infrastructure which could already be sufficient for the larger part of the seagoing fleet. The port of Rotterdam is already developing hydrogen bunker infrastructure for inland vessels and has bunker options for LNG. According to the port 80% of the deep-sea fleet can sail on LNG if there are bunker facilities is Rotterdam, Houston and Singapore. Illustrating that surprisingly few bunker facilities are needed to supply the majority of the world fleet. For the short sea fleet in Europe only Rotterdam could support the vast majority of vessels with methanol, since they would only need to bunker once every two weeks and the vast majority visits Rotterdam over that time span. This illustrates that the infrastructure challenge might not be as significant as many people image. Although it would require a change in user practices since shippers are used to having a lot of fuel on board, on average 40% when they bunker in Rotterdam, this port has cheap fuel so this could also be commercially motivated.
The supply of climate neutral energy carriers can become a challenge for growing niches, which can be dealt with by seeing grey energy carriers as a step in the right direction. The needed infrastructure development can be limited since only a few strategically positioned bunker stations can supply many vessels.

### Increased pressure and support from the landscape

Landscape actors can draw attention to negative characteristics that regime actors view as normal, such as contributions to climate change, which puts pressure on the regime to change (Geels and Schot, 2007). Without this pressure climate neutral technology might never out compete the old regime because it cannot compete on price and performance dimensions (Newig et al., 2007). Proving climate neutral technology and developing infrastructure will thus not be enough, some customers and shipowner require more incentives. The shipping landscape needs to change in favor of climate neutral shipping, by for example a carbon tax, an emission trading system, a fuel levy or subsidies for retrofits. These transition enablers will be required to speed up the pace, otherwise emissions will only grow since the niche cannot compete with the regime. All interviewees agreed that the regulations should be changed in order to allow the cluster to make a transition.

The landscape can be changed by governments at a local, national or international level. Note that a local government can only change the local landscape, which disturbs the level playing field between area's which can have undesired effects. The industry could just move to another area, taking with it all the benefits such as employment. Since shipping is such a global sector it would be best if changes are made at the IMO level, since the 174 countries that are part of the IMO would change the global landscape together.
A couple interviewees were experienced with the IMO and the difficulties with implementing radical legislation. The mantra for changing the shipping landscape has always been to maintain a level playing field, which can only be achieved via the IMO, due to the slow nature of the organizations and the urgency for change this mantra has come under pressure. The IMO works on a consensus-based approach since they have no authority to implement legislation in a country. All member states adopt the new rules in their own national system, which they will only do if they agree with them. Long and complicated negotiations are usually needed to reach a unanimous decision, which will always be a compromise. Climate change is not a top priority for all the countries, some developing countries, that are strongly depending on shipping, fear for their economy.
The EU is not content with what the IMO has delivered over the past decade and is therefore composing more ambitious plans, such as a European emissions trading system, according to interviewees. This will hurt the level playing field, some interviewees even think that vessels might drop off their cargo just outside Europe, but since 60% of the vessel in the world sail to or in Europe every year they do have some power to make a significant change.
Vessels under 24m fall under national flag state regulations, instead of IMO regulations. The Dutch government could change the landscape for these vessels. Municipalities can also implement regulations for the shipping lanes in their area, for example limiting the emissions to protect the health of their citizens.
There are thus multiple actors that can change the landscape at multiple levels, but these must be attentive that the effect of their measure will not significantly harm their own area without solving the problem.
The regulations for operations with climate neutral fuels are in many cases absent or unnecessary stringent, as was mentioned in section 4.1. Regulations can never be ahead of innovations, but should follow up quickly. All regulatory authorities, including ports, should therefore be open to changes and keep a close eye on the developments, to ensure that they will not be the party that obstructs a transition. A lot of the pressure on the cluster is coming from politics and policies, these should then not also be a barrier for the changes they want to achieve.

Not all interviewees believe that the path towards a transition will be provided by stringent regulations that make the climate neutral 'way of doing' out compete the fossil fuel one. Since they do not believe that the required regulations will be implemented any time soon, or have undesired side effects. If 'hard' regulations that prevent certain types of operation are not implemented globally it will ruin the level playing field, which all consider to be of major importance. Some interviewees believe more in starting a dialog between customers and shipowners, to make both parties commit to the extra costs of climate neutral sailing. They said: "In my view, this dialogue is the most important solution because arranging something on an international scale with a tax is simply very difficult". This is an interesting problem approach, since implementing regulations via the IMO is so complex and slow. It will require a strong sense of responsibility for the climate in the regime, but also at the customers of shipping services.

Interviewees feel that the Dutch government could improve their level of knowledge and their contributions to the transition. The knowledge of the government is based on interactions with actors and studies, which makes it sensitive for lobbying. Some feel that the government is too idealistic and unrealistic, others feel that they do not understand the crucial position they have in the transition and should gear up their involvement and support. The feeling that the government's knowledge on the shipping energy transition is generally not in-depth appears to be widely shared.
Another complaint was that they are interested in broad policy studies but not in specific technological explorations or studies that combine technology with policy. These could help to understand how achievable alternative fuels are in the coming years and what the bottle necks are. This might be because the government thinks too easy about climate neutral sailing.

The landscape barriers that were mentioned in table 2.3 were thus all discussed and confirmed by the experts during the interviews. However, the uncertainty about future price and performance dimensions, social acceptance, consumer interest and policy's and desirable solutions that was based on (Newig et al., 2007) does not only hurt the implementation of regulations. It is also a barrier for niche development and the reorientation of regime actors.

### Reorientation of the regime

The transformation pathway describes that regime actors reorient their development trajectories to find 'ways of doing' that fit with the changed landscape, they rely on niches to supply them with these new 'ways of doing' (Geels and Schot, 2007). This reorientation can start with adopting the climate neutral niche mindset, after which the other socio-technical elements follow. It can be stimulated by inspiring niche developments and pressure from the landscape, such as criticism from society.

The niche mindset is less commercial, focused on the future and proactive. They see a lot of value in being climate neutral, contributing to a better world and working together with other parties that share these interests, instead of focusing on competition. These values compensate for the inconveniences a transition will bring, they accept that not everything will be possible in the future. They believe that only 'ways of doing' that do not contribute to climate change and pollution have a place in the future, therefore one should not invest in fossil fuel technology.

The transition is seen as an urgent issue that is decisive for the future of both the earth and the production part of the Dutch cluster. Some shipping services are already in danger of being out competed by sustainable road vehicles. However, they also see that there must be a profitable business case otherwise there is no raison de d'être for companies. Niche actors are proactive and think ahead to develop profitable climate neutral business cases.

They are oriented towards technological solutions and follow the sustainable developments in the cluster. There is an interest to get a feeling with the technologies, for own use or with a future business case in mind. Instead of focusing on short term survival they try to think far ahead and develop a vision of the future and their place in it. This orientation supports niche development and is could lead to early adopters in the regime.

### The articulation and adjustment of visions and expectations on climate neutral energy carriers

The articulation and adjustment of visions and expectations is one of the three social processes in niches that is distinguished by (Kemp et al., 1998). However, the articulation and adjustment of visions and expectations on climate neutral energy carriers does not only depend on niche developments. It also depends on the direction of reorientation of the regime and multiple landscape developments such as governmental policies, regulations and fuel prices. It could therefore not be placed under one of the three previous transition enabling developments and is therefore discussed separately.

The main contenders for climate neutral energy carriers that were mentioned by interviewees are batteries, hydrogen, methanol, ammonia and bio diesel. For every contender there are believers and nonbelievers but most interviewees are hesitant to exclude any option, except batteries. People are less hesitant with making predictions for inland than for maritime shipping. Many interviewees see hydrogen as the most promising fuel for inland vessels. Hydrogen can be made relatively easy with an electrolyser and has significantly higher energy density than batteries (Castro and Mestemaker, 2019). However, hydrogen has a low volumetric energy density compared to diesel, which means that storage will require either a lot of space, a lot of pressure or a low temperature (Castro and Mestemaker, 2019). Therefore interviewees do not consider it to be a good contender for maritime shipping requires vessels to take along a lot of energy for the long journeys.

Hydrogen can be processed into methanol and ammonia which have higher energy densities and are easier stored, although ammonia is highly toxic which will require strict safety measures. Methanol is made by a reaction between hydrogen and CO2, ammonia is made by a reaction between hydrogen and nitrogen. The production of ammonia is more energy efficient and is therefore expected to be cheaper in the future (Vries, 2019). However, the capital expenditures of an ammonia installation are expected to be higher than those of methanol and ammonia fuel cells are said to be incapable of swift power changes. Some therefore expect that ammonia will be used for deep sea vessel that have a steady power requirement and for which the fuel costs are up to 70% of the total costs. They see methanol as a good candidate for short sea trade, in which the installation costs form a larger portion of the total costs due to the short sailing distances.

An advantage of ammonia over methanol is that the production is not depending on the availability of CO2, which makes it easier to be completely climate neutral. Carbon needs to be captured from the air to produce methanol, or at the exhaust and brought back to the production factory to maintain a CO2 balance. Both processes will be challenging since both capturing CO2 form the atmosphere or storing it on board will not be easy. However, some actors are confident that a solution will be found.

Bio diesel has already been successfully implemented in all kinds of vessels but there are limits to the scalability, since the space on earth is limited. It is therefore seen as a transition fuel, together with batteries and LNG. Some interviewees expect that batteries will not be a long-term solution as main energy carrier, while others see some options for vessels with a small range. This is due to their low energy density in comparison with other energy carriers. Multiple interviewees mentioned that LNG seemed to become an interesting energy carrier but that many now believe that it will be skipped by most shipowners, an example of non-linearity that leads to hype-disappointment cycles as described by (Geels, 2012) and visualized in figure 2.3. It is expected that more energy carriers will experience such a hype-disappointment cycle since there is currently no articulated vision in the sector on future energy carriers. There are still many uncertainties about future price, availability and climate neutral production capacity which makes it difficult to predict which energy carrier will be used to store the large amounts of energy that vessels require during voyages.

## 4.3 Windows of opportunity for climate neutral niche development

Landscape pressure can destabilize the regime and create windows of opportunity for climate neutral niches to develop (Geels and Schot, 2007). During the discussion of the transition barriers for the cluster it became once again clear that not all barriers are equally pronounced in the various sub-regimes, as was also discussed in section 2.6. The parts of the cluster that experience few barriers in combination with pressure or support from the landscape can become the windows of opportunity for climate neutral niches.

There are a few customers and shipowners that already see value in green services and are thus willing to pay extra. Customers are usually organizations that are very environmentally aware, such as governments, sustainable companies or individuals with a strong environmental vision. It is obviously easier when the customer is also the owner of the vessel, such as with the Rijksrederij. Examples of climate neutral services with a growing demand are offshore work on a windmill, transport of a sustainable product or recreation on a cruise. Note that higher levels of sustainability are often obtained by sailing on biodiesel, which can be done with relatively conventional technology. There are also plans for vessels that sail on batteries, which is considered to be reliable but not one of the scalable solutions.

A fixed group of partners and a fixed sailing route would help to limit the interdependency and needed infrastructure. For commercial actors, a climate neutral business case can already be achieved but only under certain conditions. Actors across the chain need to commit to a project for a long period with a customer that is willing to pay the extra cost. A long-term commitment will be needed between a shipowner, customer and energy supplier to ensure that they have a business case for a longer period of time and will win back their investments. The interviewees only knew examples of these projects with biodiesel or batteries. They say that the first truly innovative pilot projects with unproven technologies are too expensive and risky for a commercial business case. For these projects the investor should accept that there will be no return on his investment in the form of money and that the vessel can have downtime. There is also no guarantee for positive results.

The Dutch government is a noncommercial organization with large public funds and an incentive to stimulate climate neutral sailing since it is of social and economic importance to the country. Furthermore, with the Rijksrederij, navy, police and numerous customer roles it is also an active player in the shipping cluster. With the right policy they should be able to make investments and bear risks that are not feasible for commercial actors and too large for other noncommercial actors such as NGO's. Thereby they have a unique position, and according to some interviewees also a responsibility, to stimulate the energy transition by taking on noncommercial innovative pilot projects.

Although the mindset of actors is in general risk-averse there is an interest in the transition, according

to interviewees. Especially the production part of the cluster sees it as a means to ensure future competitiveness. They believe that the Dutch ship production sector can become a leader in the climate neutral vessel market, since they are traditionally good at making complex configurations work. This will ensure that the sector is future proof on both an environmental and economical level. Interviewees say that there is a willingness to design and build climate neutral vessels but that there is simply no demand for them at the moment, without a demand there is little they can do because there is no commercial incentive.
Interviewees also said that the climate neutral business case can be supported by increased awareness and concern from the public and a green certification system. When more and more consumers see extra value in a climate neutral shipping cluster and are aware of the current pollution, businesses will be pushed to pay for sustainable services. Certificates can help outsiders with selecting the most sustainable option.

In summary:

- There are already some customers interested and willing to pay for climate neutral services.
- There are some actors that deliver climate neutral services by using batteries or biodiesel. Other energy carriers are to complex, risky or expensive for a commercial company.
- The Dutch government could via the Rijksrederij stimulate the sector by doing innovative pilot projects are too expensive and risky for a commercial business case.
- The production side of the cluster is interested in delivering climate neutral vessels, since they see it as a mean to become future proof by improving their competitive position.

## 4.4 Niche development by pilot projects

The Rijksrederij is planning pilot projects, as their first step in the transition. According to section 2.2 pilot projects provide space for interactions between actors and the building of social networks, space for learning processes and the articulation of expectations and visions (Geels and Raven, 2006). They can thereby enable the step from research and development to market diffusion. This creates momentum that can be enforced through price/performance improvements and support from powerful groups (Geels and Schot, 2007). This was discussed in section 2.2 and is crucial for a transition. A pilot has the largest value when all these processes can take place. The Doing, Using and Interacting mode will also create links of communication between designer and operator, that are crucial for innovation (Jensen et al., 2007). The interviews yielded a better understanding of the development trajectory, important criteria and benefits of a pilot projects which will be discussed below.

### The development trajectory of pilot projects

The development trajectory of an innovative pilot project is visualized in figure 4.2. An incentive to start a project can come from both customers or shipowners, according to interviewees. It is then important that a multidisciplinary group is assembled with whom all parts of the project can be executed, to deal with all the interdependencies that were described in section 4.1. Furthermore, this group should have a shared niche mindset and goal, which aligns the actors and enables them to closely work together. Otherwise they will be obstructed by the mindset barrier described in section 4.1.
Next, the project leaders need to develop a plan of approach, which includes the choice of climate neutral energy carrier. This is a difficult decision given the uncertainties in prices, technology performance and energy carrier availability, as was described in section 4.1. Data from for example engine or energy suppliers can assist in dealing with the uncertainties. The project will also need funding, which probably has to be from a noncommercial source since there is a chance that the investment will not be won back, due to commercial infeasibility as was described in section 4.1. Funding can come from NGO's or governmental subsidies, their policies might effect the choice of energy carrier.
When the plan of approach has been developed and funding is secured it will be time to deal with regulatory market entry barriers, as described in section 4.1. Engineers will design a vessel in cooperation with a classification society, to ensure that the design will be granted a certificate. The regulations the operational are might also need to be adjusted, to allow operation and bunkering. This can for example

involve ports.

The following step is building the vessel with the components provide by suppliers and setting up the supply chain for the energy carrier that will be used. Actors need to decide how they deal with the costs, lifetime, required reliability and other asset properties that can form a barrier, as described in section 4.1.

When the vessel, infrastructure, certificates and crew are all ready for operation the vessel can start a test phase to get feedback on the performance. When there is confidence that the issues that occurred during operation can be resolved the parties enter the innovations cycle. In this cycle they adjust the design, fine tune components or perhaps lobby for regulations after which they go into a new test phase followed by an evaluation. This cycle of testing, evaluating and adjusting will repeat itself until the vessel meets all the demands. This can be a long and stressful period when there are many issues occurring and group member are unsatisfied with each others performance, especially when there are no clear agreements on who is responsible between actors. This can therefore form an operational barrier.

There is always a chance that an innovative project does not perform as expected and that the actors have no faith in the technology, energy carrier or each other. In that case it is back to the drawing board, which is visualized in figure 4.2 by the arrow that goes back to start. This would then be a hype that turned into a disappointment, as described by (Geels and Raven, 2006) and incorporated in the framework in figure 3.1. When the vessel does meet all the demands the project leaders have successfully demonstrated that all barriers can be breached and made tremendous developments for climate neutral sailing. This will be discussed in more detail in section 4.5.

When the vessel is followed-up by and identical vessel in the same area a lot of these steps will not have to be carried out again. All these steps have a dotted in figure 4.2, to illustrate that only the funding, classification and vessel production will need to be executed again. There might also be some engineering work that needs to be done, when the vessel has some minor changes.

The expected niche barriers that were mentioned in table 2.4 are all encountered during this described transition development trajectory of a pilot project. However, these are not fundamentally different barriers than occur at the regime level, as was assumed in section 3.1. The transition barriers are just less pronounced for certain business cases, which opens up windows of opportunity for an ambitious group of actors with a shared mindset and the possibility to obtain noncommercial funding.

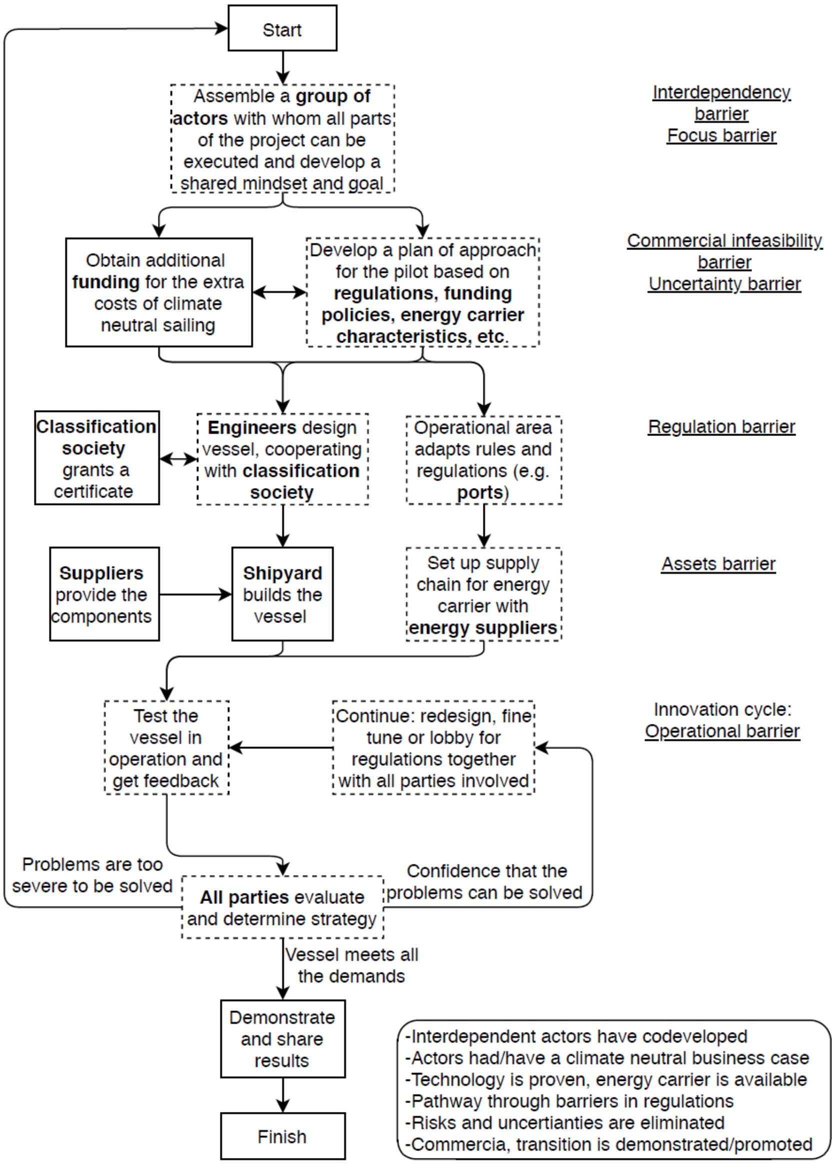


**Figure 4.2:** The development trajectory of a pilot project

## 4.5 Strategic pilot management

This theory on strategic niche management is based on the knowledge from interviewees, the pilot trajectory in figure 4.2 and the literature presented in sections 2.2 and 2.2.

The development trajectory of a pilot project illustrates the importance of cooperation between the involved actors from across the chain, due to their interdependency and the innovation cycle. Pilot projects can provide a space for interactions between actors and the building of social networks (Geels and Raven, 2006). Such interactions can for example deal with interdependencies or regulatory barriers. A shared niche mindset, as described in section 4.2, will be crucial. One can also limit the required actors when they are active in multiple parts of the chain, for example a shipyard that also does engineering.

Interviewees say that actors should make a long-term commitment to tackle the teething problems in the technology, regulations or infrastructure that will arise. These challenges should be solved together which will be valuable for the entire transition. It is common that an innovative system that works in theory will encounter some problems in practice that needs to be ironed out, this requires a space for learning processes an interaction between actors. Which is why the doing, using and interacting method of learning is crucial (Jensen et al., 2007). Pilot projects can provide the space for learning and the articulation of expectations and visions (Geels and Raven, 2006) but only with a long-term commitment and a shared mindset.

A tip from experienced interviewees, make clear agreements about who carriers the costs, risks and responsibilities for the different parts of the project. This will help in dealing with the operational barriers during the innovation cycle. However, if the shipowner demands high guaranties on reliability the production part cannot use unproven technology. On the other side, when one is investing heavily it is rational to ask for some guarantees in return. Given the uncertainty in the developments of pilot projects it can be difficult for actors to assess the costs and risks of the different parts, which makes clear agreements important.

Knowledge development will be most valuable when it concerns a scalable energy carrier, technology and infrastructure. For example, knowledge about a hydrogen propulsion system has a potentially larger knock-on effect than knowledge about biodiesel. Since hydrogen can be produced on a much larger scale and could be used by a significant part of the Dutch shipping cluster, according to interviewees. Furthermore, the gap in knowledge on the use of hydrogen is far greater than that of biodiesel. The goal of a project will be to align technology, infrastructure, regulations, market and user practices and mindset. This will include standardization, codification, model building and formulation of best practices (Geels and Raven, 2006). This will be particularly valuable for the unproved scalable energy carriers.

Projects should build on the results of other projects, and allow others to build on their projects, as is discussed in section 2.2 and visualized in figures 2.5 and 2.4. The outcomes of local pilot projects can lead to more resources and build shared rules on a higher level. Interviewees say that extra value can be created when there is a synergy between projects and the results are complementary. Some of the workload and costs can be divided between projects when they cooperate, such as dealing with rules and regulations. When multiple pilot vessels operate around one pilot bunker station it will also make the business case of the energy supplier easier. Since there are multiple technologies and energy carriers that are being considered multiple pilot projects could also be used to improve the understanding of which option is the best fit for a certain vessel type. Since no results can be guaranteed it might be wise to bet on multiple horses in the beginning and then chose one. It would therefore be valuable for niche actors to have a shared vision or even a shared plan of approach.

Both positive and negative results should be actively promoted and demonstrated to stimulate further developments that make the niche gain momentum. Developments on price and performance dimensions or powerful actors that join the niche help this process. Many actors are not certain that an energy carrier or technology will be interesting for them. A pilot project can prove the performance, but it is crucial that this is communicated to as many potential users of that energy carrier or technology as possible. This will maximize the amount of follow-up projects and develop the knowledge of actors in the cluster. A community with a shared mindset will help with knowledge sharing and attracting investors (Geels and Raven, 2006). Actors should also actively promote negative results, to prevent investments in niches that have been proven to lack potential by other projects.

Strategic pilot management in summary:

- Establish long-term close cooperation between actors from across the chain to deal with teething problems and coevolve by learning processes
- Make clear agreements on who is responsible for which part of the project to avoid conflicts
- Focus on scalable energy carriers, technologies and infrastructure to develop knowledge for the benefit of many actors and increase the chance of follow-ups and spin-offs
- Share the results and workload of a pilot to create synergy between projects, develop shared 'ways of doing' and attract more resources
- Actively promote all the results, positive and negative, to reorient regime actors in the right direction and gain resources

### Transition enablers that result from pilot projects

The transition enablers that result from pilot projects are based on the knowledge shared by interviewees (including the previous sections in this chapter) and literature presented in the theoretical framework in section 2. All interviewees from the production part of the cluster highlighted the need for pilot projects as a crucial part of innovation. Their view is thus in accordance with the theory of (Jensen et al., 2007) on the doing, using and interacting mode of learning processes. Interviewees argue that the amount of knowledge that can be obtained by doing research and calculations behind a desk is limited and not sufficient to prove a technology. One interviewee said about methanol: "There is not a lot more that we can do from behind our desks, you really need to try it out in practice for further development". Another interviewee that recently built a hybrid ship recalled that they consulted an expert to validate their design who said: "it should work, for as far as I can calculated it". This highlights the lack of knowledge that is available and the limits of the scientific mode of innovation in shipping production, which is characterized by its low production quantities.

Pilot projects can create an incentive to all interdependent actors along the chain to cooperate and align their socio-technical elements towards new climate neutral technology. They create a demand for research, development and experiments that is not provided by the commercial customers in the cluster. The investments that are needed for a pilot project will make it possible to start with developing and building supporting assets such as bunker infrastructure. All involved actors have the opportunity to receive feedback on their contributions and make improvements during the innovation cycle. This will all tremendously expand the knowledge and experience with climate neutral sailing, which will take away some of the uncertainties that are currently blurring the vision of a climate neutral shipping cluster. Furthermore, it will clarify what needs to change in regulations, and how to deal with the current regulations in the meantime. When positive results of the pilot project are demonstrated to the entire cluster it can serve as advertisement for the transition. This can be strengthened by actively communicating the mindset and the gained knowledge. As a result, the interest and trust in climate neutral sailing will increase among many cluster actors which can lead to follow-up projects, spin-offs and a reorientation of regime actors. Pilot projects can thus reduce or even take away all six barriers that were mentioned by interviews (table 4.1) and give direction to the energy transition. Although it should be noted that the effects might be limited to the energy carriers, technologies and operational area of the pilot project.

The participants of a successful pilot project will yield proven technology, energy carrier availability, a pathway trough the regulations, experience for all actors involved and marketing possibilities. These tangible and untangle assets can both be very valuable for future business cases and can also yield them follow-up projects. The experience will enable them to work more efficient and give more guarantees than their competition. Especially vessel that are similar to the pilot vessel can be made a lot cheaper and faster, since the first vessel deals with some of the uncertainties. When the demand for climate neutral vessels will pick up, the participants of the pilot will be in the best position to meet that demand. They can also build their image as future proof and receive a lot of media attention, especially when they are first to market.

Pilot projects that prove technology and establish climate neutral bunker infrastructure could eventually grow out into a green corridor with multiple vessels. Ships often have fixed sailing routes or a fixed operational area, a pilot bunker station could supply all the vessels along the route or in the area. Some operational areas have many similar vessels, such as 60m long inland transport vessel or a port full of shrimp cutters. Once a pilot project proves the operation for one vessel many others in the area can follow. Therefore, one bunker station can already make a significant difference and meet the energy demand of many vessels.

A pilot vessel can stimulate other shipowners in the area to start the dialog with their customers about the possibilities and costs of climate neutral services. When multiple shipowners make a transition a climate neutral district can be established in which the climate neutral business case is feasible for all actors along the chain. Other areas can start their own green corridor or green trade lane without having to deal with the same level of uncertainty, innovation costs and workload of the pilot project group. They can plainly copy the 'rules of the game' for a climate neutral community. This will again require multiple actors to cooperate and invest in technology, infrastructure and energy supply.

The expected transition enablers from climate neutral niche development presented in table 2.5 is thus corresponding well with the knowledge provide by the interviewees. This section has added to that knowledge by providing valuable detail and context for the specific case of climate neutral pilot projects.

Transition enablers that result from pilot projects in summary:

- A practice-based learning method of doing, using and interacting in which actors can receive feedback on their ideas and designs, this is perceived as crucial for innovation by both ship production experts and literature

- An incentive for actor from across the chain to go through the development trajectory, by engaging in long-term close cooperation, to get past the barriers and thereby develop and demonstrate new 'ways of doing', as visualized in figure 4.2
- The start of a demand for climate neutral technologies, infrastructure, energy carriers, regulations, and services
- The articulation visions and expectations of the future climate neutral shipping sector and development of stable designs due to gained knowledge and experience
- The prove that a group of actors is able to supply their service in accordance with the new climate neutral 'ways of doing', which can stimulate many other actors
- The creation of many scale-up, follow-up and spin-of possibilities

## 4.6 The case of the Rijksrederij

Being a leader in the shipping energy transition will be a challenge for the Rijksrederij since it deviates from their normal operations. Their main goal has always been to deliver reliable and cheap services to their clients within the government which they do with a risk averse mindset. The Ministry of Infrastructure and Water management is the driver behind the transition goal, this ministry is both an important client and the umbrella organization of the Rijksrederij. However, other clients do not share the transition goal and are still mainly interested in cheap and reliable services. It will be a challenge to get the other clients to support the transition plan and experiments might have to be done on the side. A pilot can build the trust in new technology for both their own organization and their clients. The Rijksrederij is a shipowner which will rely on the services and cooperation of the other actors in the chain to develop reliable climate neutral services for their clients, this will be a significant organizational challenge since many parties will need to work together efficiently. A shared vision among actors can help to align the actors.
As a leading organization in the transition the Rijksrederij will have to deal with the challenge of choosing an energy carrier and technology. The Rijksrederij expects that they will require more than one energy carrier to meet the demands of their diverse fleet, pilot projects will be used to gain knowledge about options. There current plan is to run eight vessels on batteries, about sixty on hydrogen and the others on methanol. They will use their windmills, solar panels and biomass to produce the energy carriers.
Financing the transition will require extraordinary funds since the normal income of the Rijksrederij will not be sufficient. The Rijksrederij receives money from their clients for their services, since the Rijksrederij is not a commercial organization they make no profit and use their entire income to cover their expenses. This means that there is no money for a significant increase in expenses in the traditional financial structure. To make the investments that are needed for the energy transition, approximately 300 million, money must come in from another source in the government. It should be noted that the fleet of the Rijksrederij is relatively old and that large investments are necessary anyways for a fleet replacement program. By also committing to energy transition the Rijksrederij will become future proof and will avoid large investments in the future for retrofits. The total costs of ownership might therefore be attractive in comparison with a potential future retrofit scenario.

The government wants the shipping cluster to become more sustainable, it would help if they set a good example themselves. They appear to be in a good position to do so with a large fleet of relatively small and locally operating vessels without competition. The Dutch government has large ambitions for becoming climate neutral and circular, these will have to be backed up by own actions to maintain credibility. The transition project of the Rijksrederij will surely be good for the image of the government, they do not necessarily have to lead the innovations, but they should act. The advantages of the Rijksrederij are that technology that will be used by the climate neutral fleet of the Rijksrederij can also be used by a large part of the cluster, since the Rijksrederij has a diverse fleet. A locally operating fleet will also make the innovation cycle easier since the vessels are always easily accessible. Furthermore, since it is a governmental organization there should be a way to make the necessary investments without the fear of bankruptcy.

## 4.7 Reflection on the results

This chapter has the aim of verifying and adjusting the transition framework that was discussed in section 3.1, it can be concluded that the framework and transition pathway are correct but that the elements were not always accurately described. The main lock-in mechanisms for the cluster are for example the consequence of interdependency, uncertainty, commercial infeasibility, stringent regulations and an inward focused risk-averse mindset, rather than the barriers mentioned in table 2.2. The barriers found in literature can however all be categorised under the six main ones found in the interviews.

The understanding of transition enabling developments, which originated from the transformation pathway (Geels and Schot, 2007), has gained a lot of depth in comparison with the framework from section 3.1. This has provided many insights on the challenges, but also windows of opportunity, for these developments. The addition of the articulations of expectations and visions on a climate neutral shipping cluster is one of the valuable insights. The understanding of niche development by pilot projects led to theories on the development trajectory, strategic management and the benefits of pilot projects, which is an addition to the framework and existing literature. Such a detailed theory on shipping pilot projects was not available before the interviews. The new theory on pilot project from section 4.4 has however never been applied on real pilot projects, a logical next phase is therefore case studies. These will again have the aim of verifying and adjusting the theory, which can be done by analyzing sustainable pilot projects on the basis of the new theory and discussing it with project leaders. It will also give a more in-depth understanding of such pilot projects and their contributions to the energy transition. Furthermore, they can be used to reflect on the developed barriers and enablers.

# Chapter 5

# Case Studies on Pilot Projects

The aim of this chapter is to get depth, detail and context in the understanding of pilot projects by applying the theory from section 4.4 and the methods TRL and MAC, as was discussed in section 3.3. This will also serve as a verification of the developed theory from section 4.4, since it has not been applied to actual pilot projects before. The pilot projects that will be analyzed are the ones from CMB, the planned pilot project in Lauwersoog and a Rijksrederij pilot project with methanol.

The data of the pilots will be gathered by interviewing project leaders and stakeholders and doing research into the elements of the pilot project. This will be processed into a short introduction in which the source of data will be mentioned. This is followed by an overview of the development trajectory that is visualized in figure 4.2, an analysis based on strategic pilot management based on section 4.5 and finally an analysis of the created transition enablers based on section 4.5. The methods of MAC and TRL will then be applied in an attempt of quantifying the created transition enablers. The case study ends with a reflection on the transition barriers and enablers discussed in section 4 with the gained practical knowledge.

## 5.1 Niche development by CMB.TECH pilot projects

Compagnie Maritime Belge (CMB) is a family owned Belgian shipowner which is mainly active in the global dry bulk and container transport markets. CMB.TECH is a part of CMB and has the aim of developing new technologies and implementing existing ones to make the fleet of CMB more sustainable and competitive. They were unsatisfied with the pace of development for climate neutral sailing with alternative fuels. Therefore, they decided to make the developments themselves since they see value in making contributions to climate neutral sailing. They started with the Hydroville, a small ferry that can run for up to 85% on hydrogen. This vessel was followed by the more powerful Hydrocat, which is a crew transfer vessel that will be used by an energy company for transporting technicians to an offshore wind park. The next step is the even more powerful Hydrotug for the port of Antwerp. This vessel has 8,3 times the power and 10 times the costs of the Hydroville, an impressive scale-up. These three vessels can be found in figure 5.1. The data for this case study was obtained by interviewing the managing director of CMB.TECH group together with two of his colleagues and by research on their website (CMB.TECH, 2020).

**Figure 5.1:** From left to right: the Hydroville, Hydrocat and Hydrotug from CMB.TECH

### The development trajectory

The vision of CMB is that the energy transition will be a gradual process that starts with small locally operating vessel and parties that see value in the transition. New technologies are needed which should be reliable, affordable and sustainable. A level playing field between climate neutral and fossil fuel sailing is also crucial, since they think that a transition would now mean economical suicide for their company. They believe that one needs to start with a manageable project, see what goes wrong, make adjustments and scale up. A lot of knowledge will be developed by doing and demonstrating, not only by research and talking to experts. Their mindset and vision thus corresponds well with the one discussed in section 4.2.

Funding was obtained from within the own company, this was possible because the owner sees value is developing climate neutral sailing and has the authority to make such investments without requiring permission from other parties. They prefer to develop technology without the help of subsidies, since they want to have the authority to change the development trajectory and partnerships after new insights. Subsidy providers also demand that there will be results, which means that it limits the possibility of experimental research.

Their first choice of energy carrier was batteries, after 2 months they found that batteries are too heavy, expensive and would require a very high electric power supply to charge their seagoing vessels. The focus switched to methanol, but they could not find a long-term sustainable source for the CO2, which is required for methanol production. Especially in areas where there will be a lot of cheap green electricity in the future, such as a solar park in a dessert. Therefore, they see ammonia as the energy carrier for their fleet, since nitrogen is easily captured, also in desserts, and ammonia is already transported and used around the globe. However, they decided to focus on hydrogen since they see this as a manageable first step in the transition. At that time a fuel cell would have cost 1 million euros without any guarantees about performance, and the range would have been terrible. Therefore, they decided to focus on a dual fuel solution, a combustion engine for hydrogen and diesel. Adapting a combustion engine was in their view low hanging fruit in obtaining a sustainable, affordable and reliable alternative without having to depend on hydrogen availability. Note that it is possible to use biodiesel, which enables climate neutral operation, although CMB mentioned that they had issues with the shelf life of biodiesel due to bacteria. They could not find an engine supplier that wanted to develop an engine in the beginning, so they paid for it themselves. They rented a testing center and figured out how to get the engine to work. Eventually they found an engine supplier that wanted to codevelop a combustion engine which allowed them to scale up the engine power from 300bhp to 1200bhp to 2500 bhp with 85% hydrogen. They bought a small engineering firm that had fifteen years of experience with hydrogen, to bring in knowledge for engineering and classification. They also brought in a very experienced party for the supply of their hydrogen, which was not cheap but important for a safe and trustworthy system that they themselves, but also classification societies believed in.

The classification society had very little experience with hydrogen but since CMB.TECH had brought in so much knowledge they could develop the knowledge of the classification society which led to a discount of two-thirds of the normal price. Each project scaled up the hydrogen storage system, but the design stayed the same and had been proven by the Hydroville, this made both engineering and classification easier.

The classification for hydrogen bunker facilities was remarkably easy according to CMB. They did find that the rules and regulations can be very different per area and that some authorities put their heels in the sand when they hear about hydrogen plans, while others are enthusiastic. It can therefore be difficult to copy paste a project to a new area, research into the local landscape and cooperation with local parties will be necessary. They also note that it is an advantage that there are no regulations for most systems at the moment, because these would only restrict innovations. The road to regulations will be long, therefore they are glad that the classification society and authorities are now familiar with their systems and will start to build regulations based on the knowledge they provided.

The building of the vessels is not done by CMB but at a shipyard of another company. The Hydroville, which is the only vessel that is already sailing, is a true demonstrator that does not provide any service to an external customer. This means that the vessel did not have to meet the demands of an external party, which makes the innovation cycle less important.

### Strategic pilot management

To break through the transition barrier that were listed in table 4.1 CMB closely cooperates and even codevelops with an established engine supplier, an established hydrogen supplier and a classification society. The needed partners are limited since CMB takes the lead and incorporated a lot of knowledge from partners and designed the Hydroville for own use. Initially the plan was to pay all these actors but along the way the development costs were often shared, since all parties gained a lot of valuable knowledge. CMB sees the cooperation with a limited amount of specialized organizations, while maintaining the lead, as a key to their success. They mentioned that this strategy was not a choice but a necessity since other actors found it to avant garde to take the lead themselves. Another advantage is that the needed agreements about who is responsible for performance, costs and risks at the different parts of the projects will be limited when one party is in the lead with just a few partners. Specialized and established actors bring a lot of knowledge which takes away uncertainty and the lack of trust in new technologies and energy carriers.

CMB considers their dual fuel combustion engines to be highly scalable since they believe it will soon be feasible for many shipowners. They think that their solution is reliable, affordable, sustainable and future proof for the lifetime of the vessels. With a dual fuel combustion engine that can run on 0-85% hydrogen a shipowner is not dependent on hydrogen availability or price to deliver his service with a profit margin. The extra costs and sustainability of a service can be adapted based on the demand of the customer. The extra installation costs will be limited to standardized hydrogen tanks, since the engine is not more expensive. Because the diesel provides a fallback scenario there is no need to make a costly reserve hydrogen tank for extra range. When a shipowner is unhappy with the hydrogen system, they can just take away the hydrogen storage and the vessel is still fully operational. However, unless biodiesel is used the technology is not fully climate neutral which is desired for a fully scalable solution. But it is clear that it is a significant improvement, an adaptive solution and has the potential to tremendously stimulate hydrogen sailing.

They started with an engine in a test facility and then implemented the technology in the small Hydroville. They then scaled up the vessel, engine and storage for the Hydrocat and now scaled it up again for the Hydrotug. The Hydroville had a hydrogen storage of 40kg at 200 bar, the Hydrocat has a 200kg at 350bar and the Hydrotug will have 400kg at 350bar. Thereby they built on their previous results by scaling up or adding new components to the system. By limiting the size of the steps, they also limit the risks to keep it manageable, also for classification. They are open for other organizations to build on their results, as long as they are willing to pay since CMB is a commercial organization and they invested millions.

These projects have been mentioned in press hundreds of times and CMB regularly holds presentations at conferences. They also maintain an informative website about the elements of hydrogen and its shipping applications (CMB.TECH, 2020). It could therefore be said that they are actively promoting and demonstrating their developments to make the niche gain momentum, although they themselves say that they do not have an active sales team.

### The resulting transition enablers

CMB took the lead with developing a dual fuel engine and implementing it in the Hydroville, in cooperation with established organizations. This created an incentive to develop the knowledge about hydrogen sailing in multiple crucial organizations along the chain, such as an energy supplier, classification society and engine supplier. More parties are joining such as the port of Antwerp for a Hydrotug and an energy supplier for the Hydrogcat. During these projects a lot has been learned about what is needed for safe and successful operation with hydrogen. Legislation can now be built and improved based on the experience from pilot projects. Thereby they developed new 'ways of doing'.

CMB does not quantify their developments with TRL levels or reduced MAC, as was discussed in section 3.3, but as scale up of ship characteristics along with gained knowledge and experience. Therefore, they had to start out small to minimize risks and costs. This also makes the projects less than perfect, for example bunkering with a tube trailer and a vessel without a commercial aim. But it allowed them to learn from mistakes and built knowledge by doing using and interacting. The scale up of hydrogen storage and engine power over multiple projects proves this. The larger scale would not have been possible with extensive studies or expert consultancy, they had to start practicing and proving with a small vessel.

Since the Hydroville proved the hydrogen storage system and engine in the operational environment it also eliminated the risk factor for a second vessel. All the organizations that are needed to produce a Hydroville are also aligned with each other and have some experience, which will make the project of a second Hydroville relatively easy to manage and reduces start-up costs. The extra operational expenses depend on the costs of hydrogen versus the costs of diesel. The time from idea to vessel with bunkering possibility and classification was 1.5 years. The classification of the Hydrocat took approximately 1 year, even with the experience from the Hydroville. Without this experience the entire Hydrotug project would be too risky and unmanageable. For this vessel the classification was still a large challenge, it took longer than the engineering.

CMB is already experiencing a growing demand and interest for what they are developing and see many follow-up opportunities. This can lead to further developments of their systems, regulations and the infrastructure, for example liquid instead of pressurized hydrogen storage and easier classification of hydrogen systems. They see opportunities for large environmental gain in the shipping cluster, since a transition of only a couple vessels can already make a large difference.

## 5.2 Niche development by pilots in Lauwersoog

Lauwersoog is a seaport for fishing (shrimp cutters), recreation, offshore wind, ferries and maintenance vessels. It is located on the Wadden Sea as can be seen in figure 5.2. This sea is a UNESCO World Heritage site for its large intertidal ecosystems where natural processes can function undisturbed (UNESCO, 2020). One of the vessels in this port is the Krukel from the Rijksrederij, see figure 5.2. This vessel is part of the Waddenunit that oversees fishing and recreational sailing and monitors nature. The vessel must operate in the delicate ecosystem to perform these tasks.

The port of Lauwersoog has the ambition to become a sustainable port and to make the Wadden Sea a quiet and fossil free area. A community of dedicated local entrepreneurs and stakeholder is already actively developing the hydrogen sailing niche. They want to deepen their knowledge about hydrogen and make the numerous actors in the port familiar with this new energy carrier to build trust.

The community is already doing an innovative pilot project by retrofitting a small sailing vessel, the Ecolution, with a hydrogen fuel cell. They are planning two other hydrogen fuel cell pilot projects with a shrimp cutter and a recreational vessel. A retrofit of the Krukel is now also being planned by the Rijksrederij, this would be a welcome addition to the plans in Lauwersoog.

Data for this case study was required by interviews with multiple stakeholders and the documents that they provided. These stakeholders were a board member of the foundation for a sustainable Wadden Sea who is also the owner of the shipyard that did a retrofit on the Ecolution, the program manager for the hydrogen port of Lauwersoog, the regional manager that stimulates the transition for Rijkswaterstaat, the alliance manager that is active on this project and finally the project leader from the Rijksrederij.

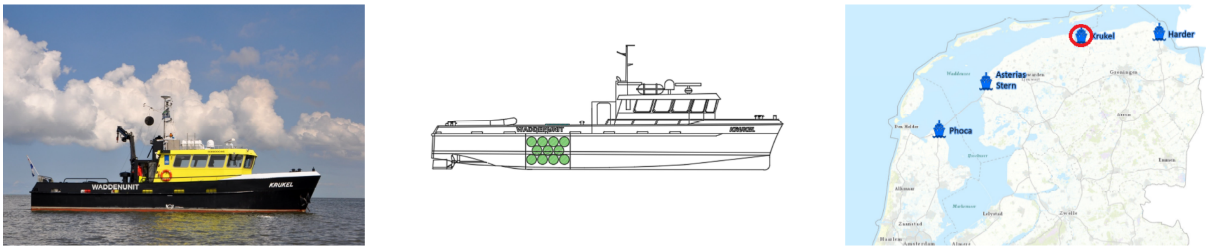


**Figure 5.2:** Left: the Krukel in Lauwersoog, a potential hydrogen pilot vessel for the Rijksrederij. Middle: an initial design sketch in which the vessel is lengthened. Right: a map of the Wadden Sea with the location of Waddenunits

### The development trajectory

The local community sees great value in not disturbing the Wadden Sea with air pollution, noise and vibrations. They feel that the current fossil fuel-based operations do not belong in their world heritage site and see this as an urgent problem. They believe that many others in the area feel the same way and therefore see options to translate possible extra costs of climate neutral practices to extra value for local customers. There is a willingness to cooperate and actors are proud that they are, or can become, the leaders in the energy transition. It can therefore be concluded that the community already has the niche mindset as described in section 4.2, the mindset barrier from figure 4.2 will thus not be a problem.

Finding investors for the pilot projects is a large challenge according to the actors in Lauwersoog. The shipbuilder expects that the first five vessels will be too expensive to get a return on investment, the risks and costs are too high. The retrofit of the Ecolution has been financed by NGO's and subsidies, since these do not have a commercial incentive. Funding for the other two projects has not yet been finalized, it is difficult to find subsidies when you cannot guarantee that your result will be commercially feasible. The plan is now to focus on one pilot and try to find NGO's, subsidies and/or businesses that are willing to produce the needed funds. Finding investors can thus be a large barrier for the pilot projects.

Choosing an energy carrier can be difficult, as was described in section 4.2. However for this community the choice is clear since they are fully committed to hydrogen, which aligns well with the vision of the northern region of the Netherlands. However, fear of hydrogen can be a barrier since some people see it is a very dangerous substance. The community has hosted gatherings for all the stakeholders in the port to educate them on the safe use of hydrogen. This is an example of how knowledge sharing and network building articulates visions on the future.

The choice for technology is also clear, they are fully committed to fuel cells. They are however dependent on suppliers, since they do not have the capacity to develop the technology by themselves. The prices of these fuel cells are now not competitive with the prices of diesel propulsion, but they drop a bit every year. They expect that fuel cells will eventually even become cheaper than diesel propulsion, but this will require a large scale up to 500000 produced fuel cells. Finding a shipyard and engineering firm that can integrate the technology will not be a barrier since one is present in the region itself. However, the Rijksrederij project will be put out to tender which means they cannot be certain who will build their vessel.

For the first pilots hydrogen can be supplied on a tube trailer, they already have a partner for this. They expect that five shrimp cutter vessels are needed to make a hydrogen bunker station commercially attractive. This illustrates the chicken and the egg barrier that was discussed in section 4.1. A demand for hydrogen first needs to be created before it can be supplied for an affordable price, but shipowners usually want to be sure of an affordable price before they make a transition. It should be noted that the plans for hydrogen production have scalability issues since the possibilities for scaling-up the solar park are limited.

The actors expect that it will be difficult to obtain a licence to operate since they feel that classification societies do not share their mindset and interests in hydrogen since they are commercially oriented. All the vessels are under 24m, so they fall under Dutch made regulations, but the responsibility for granting licenses has been laid by the classification societies. The shipbuilder is not happy with this arrangement and expects that it will be a long and difficult process. Getting a licene to operate from the prot will probably be easier since Lauwersoog has sustainable ambitions and is part of the community it can be expected that they will be open to change port regulations.

When all the mentioned barriers have been passed the vessels can be tested in operation to receive feedback. The Ecolution will be a true demonstrator and not have any operational tasks other than proving sustainable sailing is possible with hydrogen and fuel cells. The shrimp cutter, recreational vessel and Krukel do have certain operational tasks which will translate in more demanding design requirements. The experience from the Ecolution will improve the changes that the other vessel will meet their demands and limit the needed innovation cycle.

## 5.3 Strategic pilot management

It is important that the actors involved in the projects commit to a long-tern intensive cooperation, since they are interdependent and teething problems can be expected. The community in the port has a long-tern vision and is already actively building a social network for hydrogen sailing. Furthermore, they say that because it is a relatively small community with shared mindset the cooperation should not be a significant issue. Especially since the number of involved actors can be limited by actors that are active in multiple roles, one party is for example active as NGO board member, shipbuilder and engineer. Finding actors that are willing to invest can however be an issue, as was discussed. It is also still questionable what the role of the Rijksrederij can be in this community since they are restricted by tender rules, which means that they might not be able to commit to local actors. This can be a problem

when another shipyard is cheaper but does not share the mindset and commitment to long-term close cooperation, which is important for pilot projects.
The knowledge development will be most valuable when it uses a scalable energy carrier and scalable technology, both hydrogen and fuel cells are considered scalable solutions for the future. Hydrogen can be produced on large scale and fuel cells are becoming more powerful, increasingly efficient and cheaper. A practice-based mode of innovation will be a crucial step in the development of these practices.
The pilots can build on the results from the Ecolution and enable other pilots in Lauwersoog, the Wadden Sea or at other places via the Rijksrederij. Other organizations at Lauwersoog and the Wadden Sea area can see what is being achieved and be stimulated to build further on these projects, with more knowledge and less development costs. The goal of the community is to have five shrimp cutters so that they can realize their energy supply plans, eventually the long-tern goal is to have a fully sustainable port. The knowledge that is being gathered by the Rijksrederij will be valuable for achieving their goal of being climate neutral by 2030. Around 100 vessels could thereby benefit which would impact regions all over the Netherlands.
Results from the pilots of the community can be shared with other actors in the area that are interested in the energy transition and are in similar positions. The community already has contacts with other actors in the port, the WaddenSea by foundations, the Dutch army, the municipality and the province. The WaddenSea foundations can be an important channel to reach other actors along theSea that can start particularly similar projects. The actors in Lauwersoog think that their project could eventually also be interesting for hydrogen busses, energy companies like Vattenfall and the NAM, the water authority and other organizations that have sustainability goals. There are plans for a large scale-up of hydrogen production in the region in which established energy suppliers are already involved (Koster, 2020). The Rijksrederij can become a portal for communicating the results to the many other areas in the Netherlands where they are active. A small pilot project can thereby set a far greater transition in motion, but only with the right management and organizations.

#### The resulting transition enablers

Just the plans for hydrogen pilot projects and eventually a hydrogen port are already bringing many actors together and stimulating knowledge development and cooperation. People feel enthusiastic and proud to be part of the project, they try to find ways to get around the barriers as a community. This strong network of motivated local actors is likely to be very effective in solving all local challenges. However, their experience with obtaining a certificate for hydrogen sailing is limited, they might need a more established and experienced actor to convince a classification society. Large investors with a shared mindset are probably also very welcome in the community, since funding can become a problem. The local network is thus codeveloping new 'ways of doing'.
Follow-up projects that use the same technology can be 40-60 shrimp cutters, 4-6 tour boats, ferries to Schiermonnikoog and many offshore work vessels. The yearly emissions of a shrimp cutter, tour boat and ferry are up to 686, 63.3 and 1620 tons of CO2. Rijksrederij has three other Waddenunits, with yearly CO2 emissions of approximately 90 tons, and is planning to fit 60 vessels with hydrogen propulsion. Hydrogen bunker infrastructure could supply the entire eastern part of the Wadden Sea with over 150 vessel and make it easier to for example dredge the sailing routes without emissions. When the other ports and vessel in the Wadden Sea join the niche the entire Wadden sea can in time become a climate neutral area.
A unique element for these pilots is that their operational area is a vulnerable world heritage site with a delicate ecosystem, this adds extra value to becoming sustainable. The Dutch government has the responsibility to maintain this area and it would be fitting if they set an example on how to operate in this area. A pilot would demonstrate that the government takes the key values of the area seriously, local actors in Lauwersoog would really appreciate this.

## 5.4 Niche development by Rijksrederij methanol pilot

The Rijksrederij is planning a methanol pilot project with the RWS88 that sails on the canal between Terneuzen and Gent for Rijkswaterstaat. The vessel, an initial design sketch and the locations can be found in figure 5.3. This vessel will be replaced by the RWS 23, the RWS 88 can undergo a retrofit of the propulsion system and then serve as a spare vessel. This project will be done in cooperation with the Green Maritime Methanol consortium of which the Rijksrederij is a member. The aim is to obtain insights in the possibilities, challenges and costs. The plans for this pilot are limited which made the analysis of the development trajectory, SPM and yield less detailed. The data was obtained via sources inside the Rijksrederij.

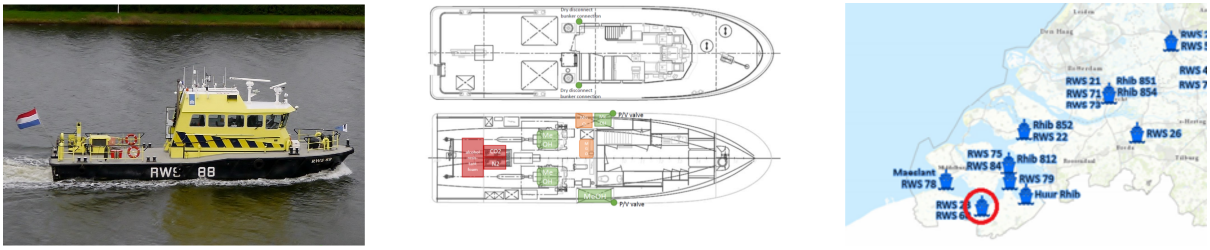


**Figure 5.3:** Left: RWS88, a potential methanol pilot vessel for the Rijksrederij. Middle: an initial design sketch. Right: the location of RWS88

### The development trajectory

Rijkswaterstaat will be the customer in this project since they want to use the vessel after the retrofit. This will make funding somewhat easier but is also likely to lead to more stringent demands. The Rijksrederij is also looking for subsidy possibilities for the funding of this project. The transition plan of the Rijksrederij is driven by Rijkswaterstaat so they are likely to see the value in developing a climate neutral methanol niche. This will most certainly also be the case for the partners of the Green Maritime Methanol consortium.

The choice for methanol resulted from an analysis of the operational profile of the vessel. Hydrogen and batteries will not be able to carry enough energy on-board and ammonia was deemed to be more complicated than methanol, which they plan to produce themselves. The CO2 that is needed for the production can in the future be produced by burning the vegetation that Rijkswaterstaat trims away. This can be considered climate neutral but is not very scalable since the amount of vegetation is limited. The current plan is to replace the diesel engines with 2 300kW engines that can run fully on methanol but maintain a diesel generator set. The Rijksrederij has yet to select an engineering firm, shipyard and suppliers for this retrofit project. They will also need to cooperate with a classification society to obtain a licence. Furthermore, they will need to find an energy supplier and a bunker location. It is yet unknown how challenging these processes will be, but support of the consortium, that contains parties from across the chain, will probably be valuable.

Going through an innovation cycle will be no problem for this vessel since it will be used as a spare. This means that downtime is acceptable and tests in the operational environment can be easily organized.

### Strategic pilot management

The Rijksrederij, Rijkswaterstaat and the consortium will all be in it for the long-term since they all have transition or development goals. This will be valuable when teething problems occur along the development trajectory. The shipyards, engineering firm and classification society might not feel the same incentive for a long-term commitment, they might just be looking for commercial gain. This could be prevented by making a shared mindset and development goal part of the procurement criteria, although this can be difficult to objectively measure. The second SPM point is clear agreements between actors, it is however yet to early to make any statements on this subject.

The explorative interviews from section 4 found that multiple experts see methanol as a potential climate neutral energy carrier for the future of the shipping cluster. This is probably the reason why the Green Maritime Methanol consortium was established in the first place. Methanol sailing is thus considered a scalable solution which means that any knowledge development can be valuable for many actors in the shipping cluster. The CO2 source for the methanol production method will however not be scalable, which means the rest of the sector will need to find another method.

The consortium will also allow the Rijksrederij to build on the results of previous developments and led others build on their results, since knowledge sharing will be relatively easy in this established network. Any positive results can be promoted by the consortium, of which many established shipping organizations are a member, or to other Rijksrederij customers that might sail on methanol in the future, such as the coast guard.

### The resulting transition enablers

This project will again provide a practice-based learning mode of doing, using and interacting which is crucial for innovation in the shipping cluster. It will identify all the problems that are related to the methanol 'ways of doing' and create an incentive to a multidisciplinary team to solve these problems. Putting a vessel on the water and operating it will be a valuable incentive to all actors involved which will lead to the much needed co-development of the niche elements.

The RWS 88 currently emits 388tons of CO2 per year, after the retrofit this can be drastically reduced since it will only use diesel for a generator. It will thereby give Rijkswaterstaat a future proof vessel which can build trust in the technology and lead to follow-ups and spin-offs in other parts of the Rijksrederij fleet.

A close cooperation Green Maritime Methanol consortium will make the project more manageable due to the established organizations and knowledge that reduce interdependency, risks and investments. It will also make the results more valuable since they can be easily shared with relevant actors in the cluster which increases the change of investments, follow-ups and spin-offs. Such a consortium will thus be a valuable network for the development of pilot projects and thereby for the entire energy transition.

## 5.5 The step in Technology readiness

The step in TRL was assessed on the basis of the methodology described in section 3.2. Data for this assessment was obtained by interviewing project leaders.

CMB started with testing the entire engine envelope of a dual fuel engine in a testing facility at every possible temperature, now they proved the system in the operational environment and scaled it up. CMB believes that the Hydroville has brought the level op to TRL 9. It is therefore concluded that the CMB pilots brought the hydrogen diesel combustion engine from TRL 5 to TRL 9 for shipping purposes.

Fuel cells are a technology with a lot of potential but have not yet been sufficiently proven in an operational environment, according to multiple interviewees. Implementing it in vessels and demonstrating its performance would therefore be very valuable, it could bring the technology from TRL 5 to TRL 8, according to the project leader. This could stimulate a demand growth, which would further improve price and performance dimensions.

The RWS 88 A step in TRL will also be able to make a TRL step, even though the green maritime methanol consortium already has other projects that will prove methanol technology in an operational environment. These vessels are however significantly larger (NMT, 2019) so perhaps it is possible to prove methanol engine technology for the 300kW range. Furthermore, the experience with methanol propulsion is currently so limited that the technology cannot be considered TRL9.

## 5.6 Reduced marginal abatement costs

An analysis of the reduction in marginal abatement costs was introduced in section 3.3.2 which included formula for the calculations. Data for these MAC calculations was collected during the case studies. The results of the calculations with these formulas can be found in table 5.1, these will be discussed in detail in this section.

### MAC calculations for CMB pilots

The cost of the Hydroville were approximately €1 million, of which €200k was for engineering and classification and another €200k was for the hydrogen storage system. A second Hydroville could thus be made for approximately €800k, since engineering and classification costs are already made. Without the hydrogen tanks the Hydroville would be a 'normal' diesel vessel and costs approximately €600k. The Hydroville was thus approximately 66% more expensive than a diesel propelled Hydroville but managed to half the extra costs for a second vessel of the same type. The Hydroville is a demonstrator project that does not replace a diesel vessel and has only a few sailing hours per year. This makes it difficult to calculate the delta OPEX and reduced GHG emissions. However, since both hydrogen and bio-diesel are

| **Vessel** | **Energy price** | **Power supply** | **Delta CAPEX** | **Delta OPEX** | **CAPEX/ OPEX** | **MAC** | **Reduction follow-up** |
|---|---|---|---|---|---|---|---|
| Hydroville | Hydrogen at 10/kg, bio diesel 3x normal diesel | Diesel-hydrogen combustion engine | 400k total /66% | +200% | - | - | 200k/ 33% CAPEX |
| Hydrotug | Hydrogen at 10/kg, bio diesel 3x normal diesel | Diesel-hydrogen combustion engine | 33k /24% | +200% | - | - | 500k / 12% CAPEX |
| Krukel | Hydrogen at 10, 5.23 and 3.93/kg | Hydrogen and fuel cell | 73.3k /275% | 0.65k/-1%, -20k/-43% or -29.4/-63% | 16.14, -4.93 or -3.03 | 1032, 766 or 637 | 28, 38 or 45.5% MAC |
| RWS 88 | Methanol 1.20/liter | Methanol combustion engine | 33.3k/100% | 179k/381% | 0.18 | 546 | - |
| Shrimp cutter | Hydrogen at 5.23 and 3.93/kg | Hydrogen and fuel cell | 83.2k/870% (only propulsion system) | 28k/19% or -45k/-31.3% | 3.53 or -1.77 | 269 or 93.6 | - |
| Lowest MAC Rijksrederij | Green electricity price scenario | Battery electric | Positive | Negative | negative | 100 | - |
| Highest MAC Rijksrederij | Hydrogen, dropts to 3/kg in next ten years | Hydrogen fuel cell | Positive | Positive | Positive | 700 | - |

**Table 5.1:** Summery of MAC calculations, - indicates that the required data could not be obtained. Note that much of these calculations are based on estimations from experts.

approximately 200% more expensive than diesel at the moment the OPEX will also be approximately 200% more expensive.

The costs of the Hydrotug will be approximately €10-11 million, of which €1 million is attributed to engineering and classification and €1 million for the hydrogen system. A second Hydrotug could thus be made for approximately €9-10 million and a 'normal' tug of this size would cost around €8-9 million. The first Hydrotug will thus be approximately 24% more expensive than a diesel propelled tug and the second one approximately 12%, the lifetime of a tug is expected to be 30 years. This already significantly less than the extra CAPEX for the Hydroville, although this can in part be attributed to the scale-up. Note that the propulsion system also accounts for a smaller percentage of the total cost of this larger and more complex vessel, which reduces the delta CAPEX. This vessel could sail climate neutral if it uses hydrogen and biodiesel, which are currently both approximately 200% more expensive than diesel. This means that the climate neutral OPEX will at the moment also be approximately 200% higher than the diesel OPEX. Qualitative data on the OPEX is not available which makes it impossible to calculate CAPEX-OPEX ratio.

### MAC calculations for the Krukel

The shipbuilder in Lauwersoog has done a technical feasibility study for the retrofit project of the Krukel. They have calculated the costs of the retrofit at €1130k, a retrofit of a second similar vessel is estimated to be 20% cheaper. However, the batteries will need to be replaced and the project leader of the Rijksrederij estimates that more work needs to be done to make the vessel ready for the next fifteen years. The costs for the hydrogen retrofit are therefore estimated to be €1.5million versus costs of €400000 for keeping the vessel alive for 15 more years with a diesel retrofit. The CAPEX will thus be 275% higher than the fossil fuel one.

The current costs for hydrogen are approximately €10 per kg, with an electrolyzer in Lauwersoog this could drop to €5.23 per kilogram, with an electrolyzer and a solar park this could even drop further to €2.93. This would require a steady demand for several tonnes of hydrogen per week. For a demand of approximately 2 tonnes per week the required energy from the grid would cost €3.99 per kg, the electrolyzer would cost €1.26 per kg and the bunker station costs €2.38 per kg. However, oxygen and rest heat can be sold which reduces the costs by €2.41 per kg, which means that hydrogen would be available for €5.23 per kg. A solar field could deliver the required energy for €1.72 which results in a hydrogen cost of €2.93 per kg.

The MAC reduction has been calculated for these three different hydrogen price scenarios for the pilot and a follow-up, the calculation can be found in appendix IV. It is based on the 2019 emissions of 73 tonnes of CO2. The MAC for the pilot is respectively €1032, €766 and €637 for the €10, €5.23 and €2.93 hydrogen per kg scenario. For the follow up this is reduced to and €741, €475 and €347 which is a relative reduction of 28%, 38% and 45.5%.

The CAPEX-OPEX ratios for the pilot are 16,14, -4,93 and -3,03 respectively. The negative numbers are caused by a negative delta OPEX which can be explained by two things. First, the retrofit is expected to use 58% less energy due to the higher efficiency of the fuel cells in comparison with the old diesel engines and to slow steaming, since the vessel will have less than half of its original power. Second, the low hydrogen prices in the last two scenarios. The project leader of the Rijksrederij estimates that these energy savings of 58% are a bit to optimistic.

The project leaders in Lauwersoog calculated the costs of hydrogen if they would produce it locally with power from the grid or from a solar field. This would require a steady demand for hydrogen, to which the Rijksrederij can contribute. However, the hydrogen demand should be several tonnes per week to produce it for €5,23 per kg with grid power or €2,93 per kg with solar power. When the Krukel only uses 4071 kg of hydrogen per year their contribution to this demand will be a marginal. If the Krukel would have made a significant contribution to this demand, such as other Rijksrederij vessels will, the reduction of OPEX could in part be attributed to the pilot.

### MAC calculations for the RWS 88

The total investment costs of this pilot are estimated to be €1million, of which €0.5 million can be attributed to normal maintenance costs since the engines already needed to be replaced. The delta CAPEX will thus be €33.3k, which is twice as high. The vessel currently uses 67.5 thousand liters of marine gas oil per year which costs approximately €0.55 per liter. The retrofit vessel will use approximately 180 thousand liters of green methanol per year which costs €1.20 per liter. This leads to an extra fuel costs of €179k which is an increase of 381%. When this vessel is used for 15 years the yearly extra costs will be €152.5k for a yearly CO2 emission reduction of 388 tons, the MAC is thus €393 per tonne of CO2. The delta CAPEX-OPEX ratio for this vessel is 0.19.

These values are strongly depending on the costs of methanol since this is main source of the extra yearly expenses. Since the current plan is to use the vessel as a spare it is also questionable how much it will actually sail, and thus how much emissions will be reduced. The needed data for estimations of how the MAC will change for a second vessel are not available.

### Other obtained MAC data

The group in Lauwersoog also made extensive calculations for a shrimp cutter. With this data four MAC scenarios can be calculated. Note that these calculations only look at the CAPEX of the propulsion system. At a hydrogen price of €5,23 per kg the MAC would be €269 and the delta CAPEX-OPEX ratio of 3.53. At the same hydrogen price but with a 50% subsidy on the CAPEX the MAC drops to €155 with an delta CAPEX-OPEX ratio of 1.76. At a hydrogen price of €2,93 per kg the MAC would be €93.6 and the delta CAPEX-OPEX ratio would be -1.77, since the opex of hydrogen sailing is already cheaper. At the same hydrogen price but with a 50% subsidy on the CAPEX the MAC drops to €-19.8 with an delta CAPEX-OPEX ratio of -0.86.

If one would invest in five hydrogen shrimp cutters in Lauwersoog the CAPEX of the second vessel is already expected to drop by 20%. For the third, fourth and fifth vessel this reduction would be even higher compared to the first vessel, due to economies of scale, engineering experience and production improvements. A sixth vessel could therefore easily be over 30% cheaper. Furthermore, they would enable the investments that make the hydrogen price drop from around €10 to €2.93, which is a reduction of 70%. This OPEX and CAPEX reduction would reduce the MAC from €636 to €25.7, a reduction of 96%. The extra costs of climate neutral sailing would suddenly be marginal, enabling many actors to make a transition. This would require investments of approximately €6 million for the solar field, electrolyzer and bunker station and again approximately €6 million for the hydrogen installation in the vessels. This last investment will not be fully won back in the form of money, since the vessels will cost more than they yield. Furthermore, the hydrogen shrimp cutters will probably have inferior performance with respect to the established vessels.

The Rijksrederij has also made MAC calculations for many of the vessels they want to replace in the coming years and found that the results differ significantly per vessel. They estimated that the OPEX cost will drop by 58% in the coming decade due to climate neutral fuel price reductions and that the vessels will have a lifetime of 25 years. The average OPEX over this lifetime was therefore estimated to be 62% of the current value. It is expected that the CAPEX could half over the next decade, but this estimation assumed that the vessels will be bought within a few years and would thus not benefit of this reduction. The average MAC of the vessels would be €380. The yearly additional costs of an entire climate neutral fleet would be €13.5 million with this MAC value, since the Rijksrederij has yearly CO2

emissions of 35kt. The lowest MAC of €100 would be achieved by electric vessels and the highest MAC of €650 and €700 by a RIB and a research vessel that collects data by trailing.
IMO's fourth GHG study also makes some estimations with the MAC with both CAPEX and OPEX scenarios (Committee, 2020). Based on (Eide et al., 2011) they assume that the capex will have a cost reduction of 50% by 2030 and 60% by 2050 for LNG with Fuel cell, Hydrogen with fuel cell, ammonia with fuel cell, synthetic methanol with fuel cell and biomass methane with fuel cell.

#### Reflection on the MAC calculations

The MAC calculations prove that there are large differences between vessels but that there are possibilities were launching customers could fully reduce the MAC. The differences in CAPEX-OPEX ratio can be explained by the used technology, fuel prices and the amount of sailing hours. The methanol combustion engines and hydrogen installation of the Hydroville are significantly cheaper than the fuel-cells with hydrogen storage that the vessels in Lauwersoog are planning to use. Calculations from the Rijksrederij show that vessels with fuel cells have a ratio around 1-1.5 while the ratio for methanol is around 0.1. The ratio for sailing on batteries is negative since the OPEX of sailing on electricity is lower than that of sailing on diesel.
The MAC is particularly high for vessel with a high power and range requirements but few yearly sailing hours, since these have a high CAPEX but a low GHG reduction. A retrofit also results in a higher CAPEX than new build since all retrofit costs are extra CAPEX, these can be reduced by using a vessel that would be written off, although costs can still be high when the vessel needs to be lengthened or severely adapted in another way. The lowest MAC comes from vessels that have a lot of sailing hours at a low power, since these could use batteries which already have a negative OPEX.
When launching customers operate multiple energy demanding vessels in one area, local energy carrier bunker and even production facilities can be installed. This could in some cases reduce the OPEX by up to 70%. Fuel price reductions of up 50% in five years and up to 70% in the next ten years are therefore expected by the project leaders. CAPEX can also be significantly reduced, experts expect that a direct follow-up can already be up to 20% cheaper and that the extra CAPEX costs of climate neutral sailing will on average half over the next ten years as a result of the demand from launching customers.
The group in Lauwersoog appears to aim for a negative MAC, apparently they expect that this is necessary for the commercial shrimp cutters in their area. The ministry of I&W is said to accept a MAC of €102 for dredging work that they are currently contracting out. The Rijksrederij is planning to accept far higher MAC values of over €400, since that is the only way to start with their transition.
Note that the results of the MAC calculation should be considered as an estimation rather than an exact calculation, since there is a lot of uncertainty in how values are going to develop over time.

## 5.7 Reflection on transition barriers, enablers and pilot theory

This section will reflect on the transition barriers, enabler and limitations of the enablers that can be created by pilot projects. The theory on the development trajectory, strategic management and resulting transition enablers will also be evaluated.

### 5.7.1 Transition barriers

The development trajectory and SPM was used to assess how pronounced the transition barriers from table 4.1 are for these case studies, which is summarized in table 5.2. Furthermore, the case studies are used to reflect on to what extend pilot projects can help to overcome these barriers.

#### The theory on the development trajectory and strategic pilot management

The interviewed project leaders and stakeholders say that the theory from section 4.4 is corresponding excellently with their own experiences. All the information of the pilots could easily be put in the concepts from the theory. This provided insights, detail and context, even when the information was limited. The development trajectories made it clear that the analyzed pilots try to establish long-term close cooperation and focus on scalable technologies and energy carriers as was described in the strategic pilot management section. However, cooperation between different pilots and sharing both the positive and negative results could be improved. It appears that the project leaders try to make clear agreements on who is responsible for which part of the project, but the information on this subject is limited.

### Interdependency

A climate neutral pilot project is clearly dependent on many parties from across the chain. CMB deals with this by establishing long-term close cooperation with established organizations that have a required expertise, they take the lead in all these cooperations. Long-term close cooperation is also the key in Lauwersoog, where it is based on a shared mission and mindset related to protecting the WaddenSea. The Green Maritime Methanol consortium is another example of long-term close cooperation of actors from across the chain, even classification societies are participating. This seams to be an effective way of dealing with the interdependecy, which corresponds well with SPM theory. Pilot projects can thus help to overcome this barrier.

### Commercial infeasibility

Even these small climate neutral pilot vessels are clearly too expensive to be commercially feasible. Actors therefore seek for noncommercial funds such as national or EU subsidies, or funds from foundations but this is not easy. CMB was able to pay for their projects with funding from within the company, but without a commercial incentive. This was probably possible since they are family owned, commercially successful and already strongly oriented to a climate neutral sector. Furthermore, their dual fuel engine technology is relatively cheap and the follow-up projects (Hydrocat and Hydrotug) appear to be somewhat commercially feasible, since the they are bought by commercial companies. It is expected that a market for fuel cell hydrogen sailing could also emerge in Lauwersoog when investments make the prices drop. Multiple pilot projects together with follow-ups can make a crucial contribution for overcoming this barrier. However, more developments will be needed to reduce the costs or improve the willingness to pay of customers.

### Uncertainty

Risks can be made relatively manageable when a small demonstrator vessel is chosen, such as the Ecolution and Hydroville, and the high risk parts of the project are carried out by established actors, such as hydrogen storage. Actors did recall a close call with a hydrogen leakage that could have ended badly, which indicates that there are still risks. The development trajectory of CMB illustrated the struggle with choosing an energy carrier. They started with batteries but are now developing hydrogen sailing, while they think that ammonia will be the best solution for their own fleet. The case studies also illustrate that the visions on which energy carriers will be used for which vessels have not yet converged at the niche level, since they differ per actor. The technological developments created by pilot projects can take away any uncertainties about their performance and energy carrier availability. Uncertainties about future prices will however remain.

### Assets

Start-up costs: retrofitting or new build of a small vessel with hydrogen or methanol propulsion already costs over €1 million. This is excluding the start-up costs for bunkering infrastructure and energy production, which are also expected to exceed €1 million. Then there are also costs for building a network and educating the crew. The start-up costs are thus high, which is normal in the shipping industry but is a barrier, especially when the project is not commercially feasible or has high risks. Pilots can help to overcome these barriers by reducing a significant amount of the extra CAPEX for follow-ups. However, extra CAPEX will remain for some technologies such as fuel cells.
Reliability: project leaders see proving the reliability as a goal, since this is important in the shipping sector, but chose pilot vessel for which down-time is acceptable. The Ecolution, Hydroville, Krukel and RWS 88 can all have down-time, but their successors cannot. Reliability thus appears to be a transition barrier that can be solved by starting with a pilot project that can have some down-time, which limits the risks of the project. Pilot project can fully remove this barrier by demonstrating reliability.
Vessel lifetime: this can be a lifetime when actors are uncertain about their choice. CMB mentioned that offering the possibility of removing the hydrogen system from their vessels was a means to deal with the

long uncertain lifetime, an adaptive design. The Rijksrederij chooses to retrofit relatively old vessels that needed maintenance anyway. However, they do this mainly because it is faster than new build, which requires a long internal process. Pilots can contribute to a solution to this problem when they develop and prove an adaptive design, but the lifetime will remain a barrier that slows the transition down.

### Regulations

A significant barrier according to project leaders. They experience a high dependency on authorities and classification societies, getting their approval requires a lot of time and effort. It is difficult to find parties that share the niche mindset and there is often a large gap in knowledge, that niche actors need to fill. The regulations and authorities also differ per location, which makes it impossible to just copy paste a project. A new locations requires a study in the local regulations and connections with local authorities. However, the gap in knowledge and regulations can in some cases also be positive since niche actors are still able to influence it. CMB proves that pilots can stimulate the development of new regulations, which was also mentioned earlier by interviewees. Regulators will react to the pilots and thereby overcome the market entry barrier imposed by the current regulations.

### Focus

A shared mindset among niche actors appears to be a key enabler for dealing with the transition barriers. Project leaders believe that pilot projects should not have a start-up mentality, since the sector is so focused on reliability and expert knowledge is required for both engineering and classification. With the costs and lifetime of assets and the lack of knowledge at authorities and classification societies established actors are needed to create trust. However, all project leaders said that this mindset is not present in almost the entire cluster, which acts as an extra barrier. It was for example difficult for CMB to find an engine supplier that wanted to codevelop a dual fuel engine and in Lauwersoog they have difficulties with working with an classifications society with a different mindset. Pilot projects can be inspiring and convincing which changes peoples mindset and helps to overcome this barrier.

| **Barrier** | **Krukel** | **Hydroville** | **RWS 88** |
|---|---|---|---|
| **Interdependency** | High: Hydrogen Suppliers, Technology Supplier, Engineers, Shipyard, Classification society, Ports, Governmental customers | Medium: Hydrogen Suppliers, Engine Supplier Experts, Shipyard, Classification Society, Port | High: Green Methanol Supplier, Engine Supplier, Green Maritime Methanol consortium, Engineering Firm, Shipyard, Classification Society, Port |
| **Commercial Infeasibility** | Medium: too expensive for service but will have a customer | High: no commercial service | Medium: too expensive but Rijkswaterstaat will be the customer |
| **Uncertainty/Risk** | Medium: manageable, according to project leaders | Medium: manageable, according to project leaders | Medium: manageable, due to Green Maritime Methanol Consortium partners |
| **Start-up Costs (Assets)** | Medium: 2,5 million | Low: 1 million | Low: 1 million |
| **Needed reliability (Assets)** | Medium: must provide service but can have some downtime | Low: does not have to provide any service | Medium: will be used as spare so downtime is to some extend acceptable |
| **Vessel lifetime (Assets)** | High: about 15 years | Low: has already served its purpose | High: about 15 years |
| **Stringent Regulations** | High: difficult to obtain certificate | High: difficult to obtain certificate | Unknown |
| **Mindset** | Low: right mindset at project leaders and possible partners, moderate at the Rijksrederij and customers | Low: right mindset at the project leaders and partners | Low: right mindset at projet leader and partners but group is not yet complete |

**Table 5.2:** The significance of the barriers explained in section 4.1 for the Krukel, Hydroville and RWS 88 pilot project, ranked as low, medium or high

### 5.7.2 Reflection on transition enablers that result from pilot projects

The resulting transition enablers sections were used to assess the transition enabling developments that are created by these pilot projects and their resulting environmental benefits. These are summarized in table 5.3.

Development of 'ways of doing': the interdependency forces actors from across the chain to start close long-term cooperation and align their visions, which leads to the codevelopment of new 'ways of doing'. The group of actors behind the pilots are aligned and future oriented, which can stimulate others. A group can start out small, for example at the CMB pilot, but attract new members when there are positive outcomes, as was also the case with CMB pilot. This can stimulate other transition enabling developments such as support from the landscape, the reorientation of regime actors or new regulations from regulatory bodies.

Follow-up possibilities: the assessed pilots are all part of a larger development plan that always involves follow-up projects. Project leaders see the developments that result from a pilot as a method to make larger transition steps manageable. These follow-up projects make sure that obtained transition enablers will be used, which leads to environmental benefits.

Environmental benefits: pilots can already make a vessel fully climate neutral but the emission reduction of follow-up projects is far greater. These can again have larger follow-ups and spin-off projects with create increasingly larger environmental benefits. The Hydroville and the Krukel can for example indirectly contribute to a climate neutral tug fleet in the port of Antwerp and a climate neutral shrimp cutter fleet in the Wadden Sea. However, how much of the environmental benefits can be attributed to these vessels remains unclear.

Transition timeline reduction: it is all but certain that these kind of pilots will be carried out by others if these actors do not do it. While the pilots form a crucial link in the transition process. If the actors in Lauwersoog succeed with carrying out there plans they will reduce their transition timeline with multiple years or even decades. However, one pilot does not necessarily lead to a significant transition timeline reduction with accompanying environmental benefits. They are however a crucial tool for a group of actors that want to make such a timeline reduction.

| **Vessel** | **Krukel** | **Hydroville** | **RWS 88** |
|---|---|---|---|
| **Codevelopment of 'ways of doing'** | Good, could be used by many vessels, operations and organizations | Good, could be used by many vessels, operations and organizations | Good, could be used by many vessels, operations and organziations |
| **Follow-up projects** | Many, Rijksrederij vessels and partners in Lauwersoog | Many, Hydrocat, Hydrotug, more to follow | Many, for both Rijksrederij and Green Maritime Methanol partners |
| **Evironmental benefits** | Direct emission reduction of 73 tons of CO2, indirect reduction is unknown | No emission reduction since no vessel is replaced, follow-ups create reduction | Direct emission reduction of 332 tons of CO2, indirect reduction is unknown |
| **Transition Timeline Reduction** | Significant, crucial link in Rijksrederij transition, enables the next step | Significant, crucial link for development of dual fuel engines, enabled next steps | Significant, crucial link in Rijksrederij transition, enables the next steps |

**Table 5.3:** The possible yield from the Krukel, Hydroville and RWS 88 project

### 5.7.3 Limitations to the transition enablers from pilot projects

It can be concluded from the reflection on the transition barriers that pilots help to overcome or fully remove all market entry or operational barriers such as interdependency, reliability, regulations or mindset barriers. They can also make a transition easier by providing clear 'ways of doing' and provide actors with manageable follow-up, scale-up and spin-off possibilities. This can lead to transition timeline reduction, which will lead to environmental benefits in the form of emission reduction. However, pilot projects cannot by themselves lower the costs of climate neutral sailing to a level where its becomes feasible for the entire cluster.

The analysis of the MAC reduction proved that pilots can significantly reduce the costs, but this differs per ship type, operational area and operational profile. Furthermore, these pilots are capital intensive and the investments will in many cases not be fully won back. Pilot projects with many different ship types, energy carriers and different operational areas will thus take away market entry barriers, but the climate neutral shipping market will still be limited due to the high costs.

Landscape pressure and the reorientation of the cluster will be required to make a transition possible. This corresponds with the MLP theory that a transition is a gradual process that depends on developments on multiple levels. The landscape could lower the transition costs by implementing regulations and improving the willingness to pay for climate neutral services in response to growing concerns about the environment. The reorientation of the landscape could also increase the willingness to pay for climate neutral services which improves the adoption of climate neutral services.

# Chapter 6

# Discussion

The Dutch shipping energy transition is a nontransparent multi-dimensional process which influences both the future of the global climate as an important part of the Dutch economy. This thesis has created knowledge and insights which can contribute to the energy transition, these will be discussed in the discussion. The knowledge development and gained insights for these four topics will be discussed below. This thesis was commissioned by the Rijksrederij, therefore the gained knowledge and insights for the Rijksrederij will also be discussed at the end of this chapter.

## 6.1 Transition barriers

The thesis developed a detailed description of the transition barriers that keep the Dutch shipping cluster locked into the established ways of doing. The current literature does not provide such a holistic overview but tends to focus more on individual problems such as technology or regulations (Faber et al., 2011; Wijnolst and Wergeland, 2009; Gilbert et al., 2014; Mander, 2017). This is illustrated by the differences between the barriers that were found in literature in table 2.2 and the barriers that were formulated based on the explorative interviews in table 4.1.

Interviewed experts often had in-depth knowledge on barriers but were unable to structure their knowledge into a holistic overview in which they recognized the mechanisms behind the barriers. An example is the barrier in regulations, which they often did not come up with by themselves but when asked about it mentioned that it was a significant market entry barrier at the moment. Another example is the mentioning of the extra costs of sustainability, which is logical from the perceptive of the established ways of doing. However, if you understand that the transition needs to happen it would be more logical to phrase it as unable or unwilling to pay for required sustainability.

The lack of a structured and holistic overview makes the already diverse problem of the energy transition even more complex. Without an analysis of the mechanism behind barriers, for example interdependency or an imbalance between investments, return and risk, the list of barriers will become unnecessary long and limit the insights it can provide. It will be difficult to develop a trustworthy transition strategy when actors cannot obtain an overview of the barriers.

Structuring the barriers that the interviewees mentioned into the six barriers that are presented in section 4.1 was challenging and required multiple iterations. The different actors described transition barriers in different ways and generally without any clear structure. The interdependency barrier was for example often not mentioned directly but was made clear by the whole discussion of the barriers. There will however be many other ways to structure them or make further distinctions to which barriers a specific actors or vessel encounters. For example, the commercial infeasibility barrier can be broken up in many different barriers, but these all result in commercial infeasibility. It can however be concluded that a structure that provided a better overview or more insights was not found during this thesis.

Another note on these barriers is that they are often more than the sum of their parts. For example uncertainty would not be a significant problem if the assets had a short lifetime and required marginal start-up costs and had provide a change for substantial profit. However, uncertainty with the long lifetime of assets and start-up costs of many millions is a strong barrier. Combining this with the fact that climate neutral sailing is more expensive while customers are often not willing to pay extra, the fact that climate neutral operations are in many areas not allowed and the interdependency and lack of focus creates a strong lock-in.

### Application of transition barrier knowledge

In section 5.7 the transition barriers that were encountered durign the pilot projects are discussed. This can, together with the theory on pilots in section 4.4, be used to substantiate a transition strategy. For example, now that it is clear that interdependency and mindset are significant barriers it is also clear that a strong and multidisciplinary group with a shared mindset will be crucial to develop a niche. The barrier of commercial infeasibility clarifies the significance of finding a source for the additional investments, by for example non-commercial parties such as the Rijksrederij.

A table to assess the transition feasibility was presented at the end of the theoretical framework based on the barriers found in literature. This table can now be improved based on the pilot trajectory that one has to go through to get obtain a climate neutral pilot vessel, it is illustrated in table 6.1. It can be used as a qualitative tool to assess the pilot readiness of an organization. The more pluses one scores the higher the feasibility, any double minus makes a pilot infeasible.

| **Bariers** | **Criteria** | **Score:**<br>**Easy= ++**<br>**Possible = +**<br>**Difficult = -**<br>**Impossible = −** |
|---|---|---|
| Interdependency | Cooperate with all interdependent actors | |
| Focus | Develop a shared mindset and goal with the group | |
| Commercial infeasibility | Obtain additional funding for the investments costs that will not be compensated by income | |
| Uncertainty | Agree on an energy carrier and technology that can be used during the vessels lifetime (and is availeble) | |
| Regulations | Adapt any regulations that prevent operations in operational area, or obtain an exemption by cooperating with a classification society | |
| Assets | Accept possible downtime in the beginning and adjustments over the vessels lifetime | |
| | Set up bunker infrastructure in operational area | |

**Table 6.1:** Qualitative assessment of the feasibility of a pilot project

Many barriers appear to be subject to the chicken and the egg mechanism. The current regulations form a barrier for pilot projects, but regulatory changes also depend on pilot projects since they drive regulatory changes. Regulatory changes are reactive to a demand for the use of new technologies and will not emerge on their own without this demand. There is also no demand for climate neutral technology since it is expensive and unproven, this will also only change when there is a demand. The same mechanism is present at infrastructure for bunkering and large scale green production of new energy carriers, which is currently nonexistent and will only change when there is a demand. A disruptive change in demand for climate neutral sailing is necessary to change all these interdependent lock-in mechanisms. Another way to look at this is based on the MAC, the higher the adoption percentage the lower the MAC will be. When the MAC is too high for the next phase of adopters the transition comes to a standstill, or is never set into motion.

### Limitations

The number of actors that were interviewed was limited but the resemblance in their answers instilled confidence in the validity of their answers. Verification was done by sending the interview transcripts to the interviewee and asking if what is stated was correct, five responses were received which can be

considered as a moderate response rate. It would have been interesting to receive feedback on the found transition barriers and their significance by distributing a survey. However, industry experts discouraged this since they expected a poor response rate and difficulty with finding a fitting group of participants.
From the actors that are visualised in figure 4.1 only energy suppliers, classification societies and part of the regulatory bodies where not fully represented by the participants of the semi-structured interviews. Energy suppliers were initially seen as exogenous, since their fuel prices are part of the landscape. However, both the price and supply of fuel will be reactive to a demand of for example launching customers. The case studies did provide some insights into this mechanisms. Classification societies were also initially not seen as a significant party and therefore not included into the group of actors that were invited for the semi-structured interviews. The other interviewees had extensive experience with classification and could thus, fortunately, provide the required knowledge. Interviews with other regulatory bodies, that could for example change regulations in the sector, were limited to one actor at the ministry of economic affairs. The actors that are able to implement regulation such a carbon tax were assumed to be unavailable, since they would be too high up in governments.

## 6.2 Transition enablers

Theories on transition, strategic niche development and innovation (Jensen et al., 2007; Geels and Raven, 2006; Geels, 2012; Newig et al., 2007; Geels, 2012; Kemp et al., 1998; Geels, 2002) formed the basis for an analysis of the developments that can enable the maritime cluster to make a transition. They were applied to the specific case of the maritime cluster that is characterised by its large diversity in user cases. These led to an insightful transition framework, in section 3.1, that divided transition enabling developments into pressure and support from the landscape, niche development and reorientation of the regime. Such a framework for specifically the maritime energy transition was not found during the literature study, it can be seen as an important development in conceptualizing the energy transition of Dutch shipping.
The explorative interviews provided many insights into the development trajectories and also added the articulation and adjustment of visions and expectations on climate neutral energy carriers. Many interviewees again had difficulty to clearly structure the required transition enabling developments, probably since these are multiform and depending on many different characteristics, as is also the case with the barriers that create the requirement for transition enablers in the first place.
Structuring the knowledge provided by interviewees proved, again, to be a challenge that required multiple iterations. This resulted in the current discussion which focuses on the opportunities and challenges of the four transition enabling developments. Such an overview was not found in literature but does provide a clear structure and insights, which could thus be valuable for many actors who are active in the transition.

### The transition enabling effect of consortia

A consortium, with actors from across the chain that codevelop new 'ways of doing' by participating in projects such as pilots, seems to be the best solution in creating transition enablers that break down barriers. Especially when this consortium also contains many customers, regulators and classification societies, since these appear to be the most difficult actors to get on board and can deal with commercial infeasibility and regulatory barriers. Such a consortium can lead to many projects of which the results can be easily shared to articulate expectations and visions and converge the developments into stable standardized designs. The green maritime methanol consortium will probably proof itself very valuable in dealing with all the six barriers from section 4.1.
The Green Maritime Methanol consortium focuses on short sea shipping, since they expect that methanol can become a feasible energy carrier for short sea sub-regimes in the coming decade. The Netherlands has many actors that are active in these sub-regimes since the port of Rotterdam is an important short sea port. The consortium therefore focuses on these Dutch short sea actors. An ammonia or hydrogen consortium could also be valuable for the energy transition. Multiple consortia can coexist since they focus on a different parts of the cluster. Ammonia is seen as a potential energy carrier for deep sea shipping, which is a global system. Such a consortia should thus try to include relevant actors from around the globe. A hydrogen consortium should instead focus more locally, for example on the Wadden sea area, since this already includes all relevant actors for a hydrogen based sub-regime. Multiple

hydrogen consortia could then be established for different regions the Netherlands, each starting its own local hydrogen system. Knowledge sharing between these consortia would again stimulate their development.

During interviews it seemed that niche actors often have no or only limited knowledge of similar projects that are going on or have already been done in other regions. Which is a shame since both developments and mistakes will be made multiple times, which slows down the transition. Furthermore, the different niche actors do not always share the same visions and expectations for the future, which is a barrier for collaborations that could be solved by stronger connections between actors.

#### The transition enabling effect of emission reduction targets

The emission targets that are set by the IMO, EU or the Dutch green deal make barely any distinction between vessel types, operations or operational area. The distinction is often limited to inland or seagoing vessels, while the costs and willingness to pay for emission reduction differ significantly, as was discussed in this thesis. Climate neutral sailing could therefore already be achieved by 2030 or even 2025 in some cases, both on a technical and commercial level. There are for example ferry's in the Netherlands that sail to the other side of a canal, river or lake for which a full transition appears to be feasible within a couple years, if it is not already feasible. There are also many fixed sailing routes for small inland transport vessels and many small recreational vessel that could make a transition in the coming decade. However, this will not happen when there are no incentives for the shipowners and no tools to support their transition. Transition plans, targets, or deals do not provide an incentive nor the required support for these potential launching customers, which is a missed opportunity for creating a large group of early adopters in the coming decade. Customization of transition targets and support could be a transition enabler that leads to a significant transition timeline reduction and thus large environmental benefits.

It is also remarkable that the government is on the one side trying to enable a transition to meet climate agreements but on the other side also a barrier for the transition by the regulations that they have imposed. New regulations could therefore be a transition enabler. The more disruptive the better, but more disruptive also appears to be more difficult to implement. Especially on a global scale which requires an agreement between the 174 member states of the IMO

#### The social technical elements

This thesis used the socio-technical elements described in (Geels, 2012) which are technology, infrastructure, regulations, market and user practices and mindset. The theory suggests that these are strongly aligned and can therefore not independently change. For example, a change to climate neutral technology require new infrastructure, regulations, market and user practices and mindset. Two suggestions can be made after this thesis.

First, the mindset of actors is able to change independently from the other socio-technical elements and is thereby be the first step towards a transition. For example, a regime actor that is aligned with diesel technology, infrastructure, regulations and market and user practices can independently reorient their mindset towards climate neutral operations. When possible, the other elements will follow and the actor makes a transition. If this is not possible the actor remains locked-in but can already start to support the niches and reorient the development trajectory.

Second, include energy carrier as one of the socio-technical elements, since the sector will have multiple energy carriers that requires the alignment of the other elements. The energy carrier has strong connections with technology and infrastructure but is itself not part of these elements. Furthermore, it also has strong connections with regulations, mindset and market and user practices.

## 6.3 Pilot projects

A specific focus was paid to pilot projects since this is a clear and valuable contribution to the energy transition from launching customers, such as the Rijksrederij. Literature on practice-based modes of innovation and strategic niche management formed the literary basis for this part of the study (Jensen et al., 2007; Geels and Raven, 2006). This was verified and added on by interviews with experts and case studies on pilot projects. It was not possible to study the results of a large number of pilot projects due to their scarcity and time limitations. It can therefore not be concluded what changes in TRL, MAC or transition timeline a pilot on average yields. However, it was possible to develop and verify theory on the trajectory, management and possible yields of pilot projects and obtain a number of insightful data points for the MAC. The verification of the theory was done by presenting the theory to 6 experts that have experience with managing pilot projects, in separate presentations. They mentioned that it corresponded well with their experience and had no suggestions for adjustments.

An overview of the development trajectory was based on the barriers, needed developments and practice-based mode of innovation, such an overview was not found in literature. It can be used to make a quick analysis of the trajectory, management and possible yield of a pilot, as was demonstrated in the case studies. These illustrated the need for expertise at many different levels and enabled a reflection on the transition barriers and enablers.

An in-depth reflection on the transition barriers that are target and encountered by pilot projects has already been provided in sections 5.7. The limitations of the transition enabling effect of pilot project has already been provided in section 5.7.3. These subjects will therefore not be discussed again in this section.

The TRL assessment further proved that pilot projects can significantly develop the technologies that are required for climate neutral sailing. This assessment did, unfortunately not lead to further insights, unlike the MAC assessment. The attention paid to the TRL was therefore limited.

## 6.4 Further application and development of the MAC reduction method

The method of assessing to which extend the MAC can be reduced by pilot projects provided many insights in both the transition enabling effect of pilot projects and the transition pathway. This method could be elaborated when more data points are obtained, which could be used to further substantiate transition management plans. It would be interesting to obtain an overview of the adoption percentage at a certain MAC, and how this develops over time. A sketch of a possible result is presented in figure 6.3. In this case a MAC of over €300 would result in an adoption percentage of only 2.5%, but when this is reduced to €100 half of the actors would adopt a the new 'ways of doing'. This is perhaps somewhat optimistic but could be possible for certain business cases.

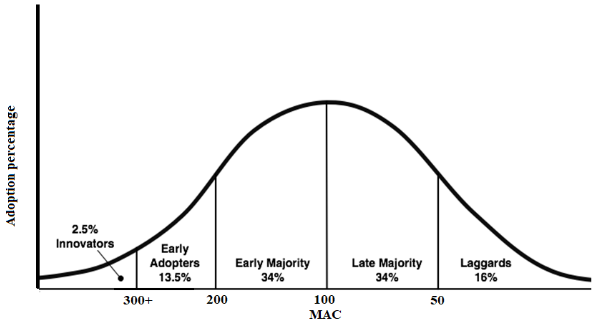


**Figure 6.1:** Sketch of the possible relation between MAC and adoption percentage for a certain new 'way of doing' and vessel

The theory could be further elaborated by scenarios on how the MAC will develop over time. This MAC estimation can be subdivided by an estimation of the development of the CAPEX and the OPEX. This will then result in a certain adoption percentage over time by matching the MAC with the adoption scenario in figure 6.3, which will again result in the percentage of the fleet that has adopted the vessel. When a certain vessel type has a lifetime of 30 years only 3.33% of the fleet will be replaced every year. This results in a long transition timeline of at least 30 years, even when the adoption percentage reaches 100%. This is illustrated by figure 6.2, which is a sketch of how scenarios for OPEX and CAPEX could predict the adoption percentage and percentage adopted for a certain vessel type. This illustrates how strongly embedded fossil fuels are due to the vessel lifetimes. For this example a fictional hydrogen vessel is chosen, therefore the CAPEX-OPEX ratio is 1. It is assumed that launching customer create a strong demand in the coming decade that enables energy suppliers to build production and bunker infrastructure that will take away the extra OPEX. This demand will also strongly reduce the engineering, certification and production costs of climate neutral sailing, but fuel cells and hydrogen storage will remain more expensive than diesel engines and their fuel tanks. The adoption percentage is calculated in response to the MAC with the help of figure 6.3.

Figure 6.2 illustrates that, even when the MAC in reduced significantly in the coming decade, the percentage that would have adopted hydrogen sailing would be around 70% in 2050 for this vessel typ. This could only be improved by an even lower MAC that makes retrofits feasible, by for example new regulations such as a carbon tax or subsidies. A scenario without launching customers in the next ten years would however slow the transition down by many years. It is difficult to imagine regulatory measures that achieve the same environmental benefits without launching customers in the coming decade. It should be noted that these kinds of calculations will always be strongly dependent on scenarios, which can lead to low reliability.

Figure 6.2 is based on a hypothetical vessel that sails on hydrogen with a MAC that is based on a specific vessel type. When a demand growth of a different vessel type would lower the hydrogen price, lower the costs of hydrogen sailing components and lead to the implementation of regulations that support hydrogen sailing, the MAC of other hydrogen vessel types would reduce by almost the same amount. However, MAC of vessel types that sail on ammonia or methanol would not have reduced at all. A study of the MAC can thus lead to a better understanding of the knock-on effect for other vessel types. For example, the CAPEX-OPEX ratio of methanol sailing shows that the MAC can for 90% be the result of the methanol price. When this price is reduced by 10% the MAC of other methanol vessel types would reduce by approximately 9%, but the MAC of hydrogen vessel types remains the same. This suggests that a launching can have a high knock-on effect on the MAC reduction for other vessel types that sail on the same energy carrier, but a marginal effect on the MAC of vessels that sail on a different energy carrier.

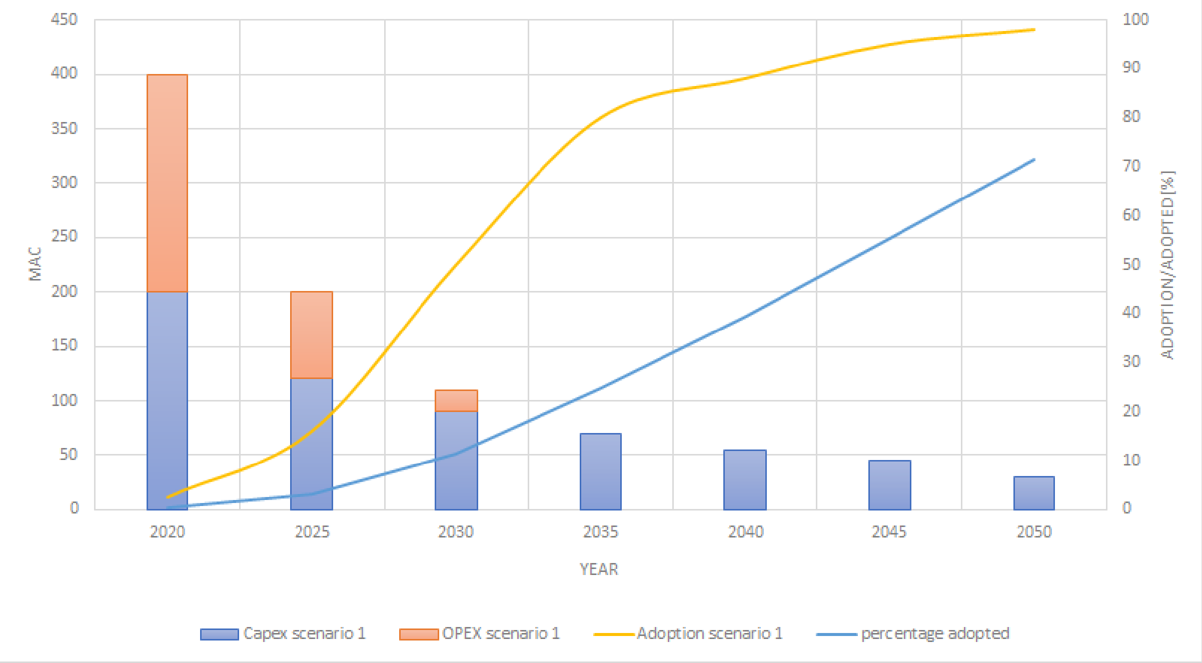


**Figure 6.2:** A sketch of how scenarios for OPEX and CAPEX could predict the adoption percentage and percentage adopted

The percentage adopted graph from figure 6.2 can be used to calculated the total emission reduction when the fleet size and yearly emissions are known. For example, when the average percentage adopted over the next 30 years is 33%, there are 1000 vessel of this type and yearly emissions of these vessels are 100 tonnes of CO2 equivalent one can easily calculate that the emission reduction amounts to 1 million tonnes of CO2. A different CAPEX and OPEX reduction scenario leads to another adoption graph, percentage adopted and reduced emissions. This is illustrated by figure 6.3, which contains the adoption scenario of figure 6.2 and another scenario with an adoption curve that lags 5 years behind, as a result from a lack of launching customers for example. The average percentage adopted over the next 30 years is 29.4% for scenario 1 and 19.4% for scenario 2, this means that in this hypothetical scenario the launching customers from scenario 1 contributed to 50% more emission reduction over the next 30 years. The area below the adoption graph is the percentage adopted times time, this illustrates the reduced emissions. The difference between scenario 1 and 2, the dark blue area, illustrates the 50% extra emission reduction that results from the 5 year difference between adoption curves.

It can be expected that the adoption percentage rises quicker when it is starts later, due to developments of for example fuel or engine prices. However, it will be almost impossible to make up for the lost time when an adoption curve starts later, since the percentage adopted has a maximum of 3.33% due to the vessel lifetime. Compensating the difference in the first five years requires a significantly higher adoption percentage, but that is not possible when the percentage is already close to 100% for the other scenario, as is the case in figure 6.3. The effect of the early rise in adoption will thus keep impacting the total emission reduction after 2050, since scenario 2 will not be able to get closer to scenario 1 due to the high adoption percentages at that time.

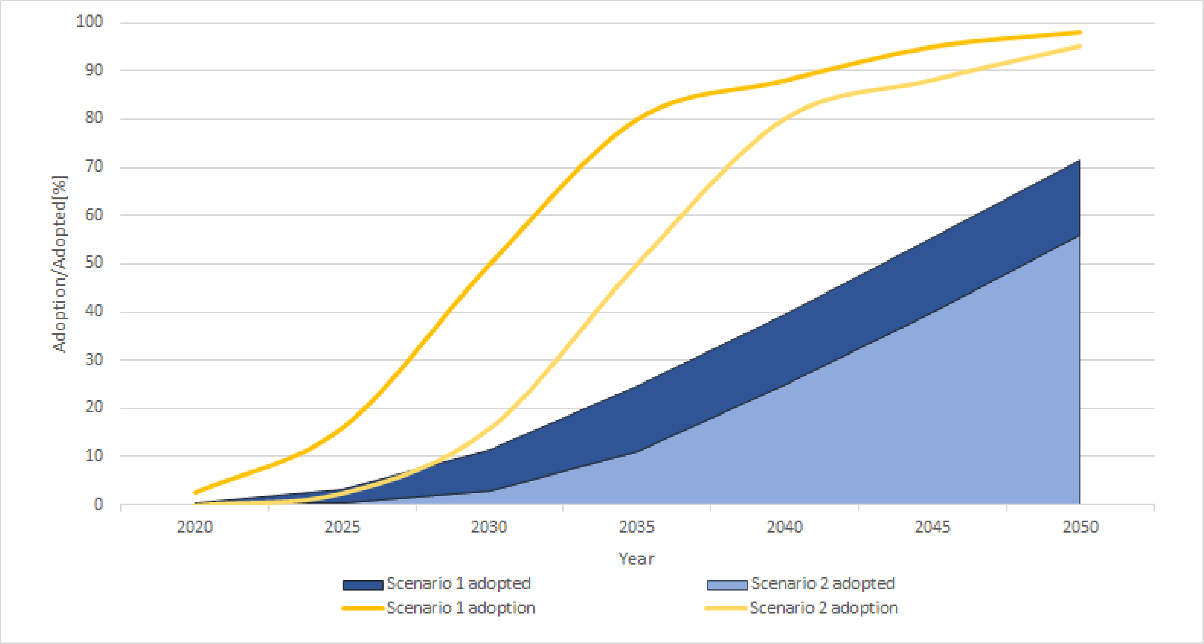


**Figure 6.3:** Two adoption curves that start 5 years apart with the resulting areas for percentage adopted, which illustrated the difference in emission reduction

### Leadership and responsibility in the transition

The shipping sector seems to lack leadership on both global, national and local scale. The global authorities have a lack of power and are slow and unambitious due to their consensus based approach. National and local governments appear to lack the knowledge and sometimes even interest in the shipping sector. The Dutch government is present in the cluster as a regulator, shipowner, customer, owner of multiple ports and possibly as an investor. All these roles give the government a great power potential. However, the different parts do not appear to be working together effectively and a shared goal appears to be missing. Some actors and branch organizations are large and powerful enough to do successful lobbying but not to an extend that they are in charge. Therefore, the question is if there is actually any actor within the sector with significant power, knowledge and capabilities to make radical changes. Furthermore, who is actually responsible for the emissions of the sector and the reduction of these emissions.

It should be clear that when you are active in an industry that is consciously endangering the future of human life on this planet you have a moral obligation to contribute to changing the ways of doing, even when there are transition barriers and low margins. However, many actors do not appear to feel this way, they rather focus their attention on discussing the costs and disadvantages of climate neutral sailing, the challenges for their organization or just ignore it and go on with their day to day business. Many interviewees could reason that they were sadly not in a position to make any contributions, although they did find it important. At the moment they can do this without experiencing any disadvantages, that should change because the reorientation of the regime can be a powerful transition enabler.

It would be a great stimulus for the transition when all companies join a project, consortium or other development project. CMB is a commercial company that actually managed to start new projects and some organizations were able to join the green maritime methanol consortium, but most actors appear to remain inactive. Since no one seems to be in charge over the sector it is difficult to find an actor who is able to force actors or create an incentive. Increased pressure from both society and niches could be the solution, by increased social awareness of shipping emission and leading niche actors that demonstrate a new 'way of doing', possibly with assistance of a consortium. However, the media seems to focus more on aviation and road transport at the moment. Shaming actors that make large contribution to climate change could be a solution, as is common in other sectors. This could make actors feel responsible for their emissions and commit to change. It will however be challenging since the sector is nontransparent and most people probably feel distanced from it, since they do not have direct contact with the shipping cluster in day to day life. A solution could be some kind of assessment system that publicly rates the sustainability of shipping services.

## 6.5 Rijksrederij

The case of the Rijksrederij was discussed on the basis of gained knowledge in sections 2.7, 2.4 and 4.6 and for the retrofit project of the Krukel and RWS 88. The barriers, environmental benefits and role in the energy transition have thereby been discussed for the Rijksrederij. The discussion on their possible role in the energy transition can build their understanding of the special position they have and stimulate them to exploit it in favor of the energy transition. They can use the results of this thesis to address to the rest of the government what they can achieve, to gain their support.

The analysis of the Rijksrederij transition project was limited by the fact that their transition plans are also limited at the moment. This makes it difficult to obtain a clear overview of their transition path and the environmental benefits they can create. This thesis therefore relied on theory and reasoning to get to the conclusion rather than data analysis. The conclusions are therefore also mostly qualitative rather than quantitative of nature.

The transition plans of the Rijksrederij are still suffering under a lack of trust from employees within their own organization who believe it is not possible. They also prioritize stable operations over sustainability, which is understandable given that the main objective of the organization is providing services to their clients and not stimulating the energy transition of Dutch shipping. However, when the Rijksrederij does not stimulate the transition by launching customership it is highly likely that there are no other organizations that will pick-up this task, at least not with a similar favorable position Furthermore, the Rijksrederij will need to replace many of their vessels in the coming decade, since their average vessel age is 22 years, if they choose to replace these by fossil fuel ones they are likely to emit a substantial amount of GHG for the next 30 years. This will probably not be appreciated by the coming generations.

It is to some extend unclear who is in charge and who is responsible for the transition of the Rijksrederij. The transition goal was set by Rijkswaterstaat, but they did not receive the necessary funding. Their clients, who are all governmental organizations, did not request the transition goal and are currently not willing or able to pay for the transition. Their first objective is to receive a reliable service from the Rijksrederij, their second is to have this service affordable and then maybe third comes sustainability. The Dutch cabinet is in charge of the ministries, so they should decide who is going to pay for the Rijksrederij transition. However, getting this subject on their agenda is not easy. The governmental structure of having a new cabinet every four years can also obstruct such long-term plan.

The desire for stable and affordable operations should not be accepted as an excuse for contributions to disastrous climate change, which will also be costly for the Dutch government. It is clear that the Dutch government is fully aware of the consequences of climate change and that the Rijksrederij is currently emitting GHG. They should therefore lead by example and get their own organizations in order, which will enable others to follow. The Rijksrederij will only be able to make a transition if they can cover the extra costs of climate neutral sailing, the only way to obtain the necessary funds is from withing the government.

# Chapter 7

# Conclusion

The conclusions of the research question and the three sub-questions are provided below. The conclusions on the sub-questions substantiate the answer of the main research question.

## 7.1 Main research question

**What are the transition enablers that can be created by launching customers in the energy transition of the Dutch shipping sector?**

It can be concluded that launching customers play a crucial role in the shipping energy transition by lowering the marginal abatement costs by tens of percent, removing operational barriers and creating a clear vision on climate neutral sailing practices. They provide a practice based learning mode which is crucial for innovation in shipping technology and enables actors to realign their technology, infrastructure, regulations, market practices, user practices and mindset with climate neutral 'ways of doing'. Furthermore, they will create a demand for climate neutral technology, infrastructure, supporting regulations, energy carriers and other services which improves their price and performance.

Launching customers are however scarce, due to the interdependency of actors in the cluster, the commercial infeasibility of climate neutral sailing, the uncertainties surrounding climate neutral sailing, the required assets which have high costs and long lifetimes, regulations and an inward focused risk averse mindset. It can be concluded that the Rijksrederij is in an unique position for launching customership due to their noncommercial nature, local operations, transition goal and opportunity of obtaining large public funds without distorting the level playing field in the sector. Furthermore, they have over 100 vessels of various types that cover the entire Dutch operational area which means that their developments will also reach the entire Dutch operational area and various vessel types.

The Rijksrederij will rely on many actors in the Dutch cluster to execute their plans, since their capabilities are limited to owning and operating vessels. This will stimulate both the environmental and competitive position of the entire cluster, but also require substantial additional funding which is yet to be secured. Furthermore, the costs of climate neutral sailing will likely remain to substantial for the larger part of the shipping cluster, even after launching customership by the Rijksrederij. Regulatory changes, a reorientation of shipping cluster actors and a willingness to pay for climate neutral services among customers will be required to make a transition possible for the entire cluster, which will then still be a gradual process of multiple decades due to the long lifetime of shipping assets.

## 7.2 Sub-Questions

**What are the transition barriers that obstruct or slow down the energy transition of the Dutch shipping sector?**

It can be concluded that transition barriers in the maritime cluster result from interdependency, commercial infeasibility, uncertainty, the required assets, regulations and the mindset of actors. These barriers amplify each other which leads to market entry barriers or a small market potential. Case studies showed that commercial infeasibility is likely to be the most persistent barrier in slowing down the transition since the extra costs of climate neutral sailing are significant and complicated to remove.

Transition theory focuses on the alignment between regime elements (such as technology, infrastructure, etc.) that creates stability to the extent that only incremental changes are possible to the regime. Maritime specific literature focuses on the strong status quo in vessel design, slow and complex governance structure, risk averse and conservative mindset, lack of competitive alternatives and lack of knowledge.

The analysis of the expert interview transcripts concluded that the main lock-in mechanisms in the shipping cluster are a consequence of interdependency, uncertainty, commercial infeasibility, stringent regulations and an inward focused risk-averse mindset. A climate neutral service is in general depending on the support of a customer, shipowner, port, energy supplier, financial institutions, shipyard, engineering firm, classification society and regulatory authorities.
It is currently unclear what the optimal climate neutral alternative is and if there will be enough, or even any, customers that are willing to pay the extra costs, which are also uncertain, according to the interviewees. Actors are in general commercial businesses that require some level of certainty about the profitability of their business case before they make large investments. This lock-in mechanism is strengthened by the strong competition, lifetime, costs, low production quantity, international nature and need for proven reliability of the required assets such as vessels, bunker infrastructure and green energy sources.
The regulations for operation and certification, such as IMF codes, are based on the established ways of doing which often restricts or even prohibits climate neutral alternatives. They also allow actors to pollute the environment without significantly paying for it, this limits the commercial incentive for sustainability.
Actors in the cluster feel that the room for experimentation is limited by the competition in the sector that lead to small profit margins, they focus more on surviving than contributing to the energy transition. They are risk-averse and focused inward. They therefore see only limited opportunities for change without the support of customers or governments.

The case studies showed that successful pilot projects can, in time, take away all market entry barriers that result from interdependency, uncertainty, the required assets, regulations and mindset for a certain ship type and operational area. However, the additional costs of climate neutral sailing can still be hundreds of euros per tonnes of CO2 equivalent which probably leads to a very small market for climate neutral services. Furthermore, the pilots require investments of millions of euros and the process of dealing with regulations is likely to be long and complicated.

The situation of the Rijksrederij is different since they have no competition, only deliver local services to other governmental organizations and have the ambitious goal of being climate neutral in 2030. However, they do depend on many other actors, such as engineering firms, shipyards, classification societies, energy suppliers and ports. They will also have to deal with stringent regulations and uncertainties in the development trajectory of climate neutral sailing and it should be noted that their transition goal is not supported by all their clients. Furthermore, they have yet to organize funding and they experience a lack of trust within their own organization for the 2030 transition goal from .

### What transition enabling developments are required to create a pathway to a climate neutral Dutch shipping sector

It can be concluded that the shipping energy transition will be a gradual process that is driven by the development of climate neutral shipping practices in niches, the reorientation of the established cluster actors and exogenous landscape parties that pressure the cluster to change and support the niches. The articulation of visions and expectations on what the future climate neutral shipping cluster will look like will also be an important transition enablers since it makes commitment and investments less risky.

It can be concluded from the literature study that the shipping cluster will follow the transformation pathway as described by (Geels and Schot, 2007), which is characterized by pressure for change coming from outside the sector, niches that develop new 'ways of doing' and cluster actors that reorient their development trajectory to adopt niche practices in response to the landscape pressure. The energy transition is thus a gradual process resulting from transition enabling developments on multiple levels which should eventually lead to a change in energy carrier, technology, infrastructure, regulations, market and user practices and mindset. Developments are necessary for all these elements since they are interdependent.

A fourth transition enabling development was identified during the interviews analysis, the articulation and adjustment of visions and expectations on climate neutral energy carriers. Interviewees see batteries, hydrogen, methanol, ammonia and bio diesel all as possible energy carriers, although opinions differ due to an ongoing discussion on their characteristics. There are many uncertainties about the production, transport, storage, availability, price, scalability and regulations of climate neutral energy carriers, which is partly due to a lack of experience. The same goes for the new technologies that will be needed to run on these climate neutral energy carriers, many of the technologies that are required for a sector wide transition are not yet on the market or have never been proved in an operational environment. Clarity of which combination of energy carrier and technology is affordable, reliable and sustainable will be crucial to make the transition gain momentum. It will provide a clear development trajectory and enable actors to start investing in their assets without high risks.
The shipping cluster is characterized by a wide variety in vessels, operations and organizations which make the already multidimensional energy transition increasingly complex. It is expected that there will be multiple energy carriers in the future with their own accompanying technology, infrastructure, regulations and user practices. This means that there will need to be multiple development trajectories for these different energy carriers happening in parallel, each will have its own timeline, which can be shortened by transition enabling developments such as pilot projects in niches.
It can be concluded that regulatory environmental developments are threefold, allowing climate neutral operations, supporting climate neutral development and putting pressure on the incumbent ways of doing to stimulate a transition. Allowing climate neutral operations consists of developing IGF codes for climate neutral technologies and changing the rules in ports and other areas to support the safe use of climate neutral energy carriers. Supporting climate neutral development consists of subsidizing projects that have the potential of making large contributions to the transition have additional costs that cannot be won back. For example, pilot projects that gain experience with new technologies, which can lead to more than double the costs and lower reliability. Commercial customers are not willing to pay these additional costs. Putting pressure on the established ways of doing can be done by a carbon tax, fuel levy, emission trading system or other measures that make the polluter pay. This will impact the competition between the established and climate neutral ways of doing in favor of the climate neutral way.
Interviewees that are actively developing climate neutral sailing feel that the energy transition should be seen as an urgent problem for both the environment and the future competitiveness of the shipping cluster. Markets and users should value climate neutral sailing and be willing to endure extra costs or inconveniences with operations. Since the transition will impact everyone there should also be a widespread interest and eagerness to contribute. This can be stimulated by leading actors that actively carry out that mindset and demand climate neutral services.

It can be concluded from the case studies that launching customers can establish climate neutral niches with their pilot projects. These will then be able to bring the transition enabling developments from niches which were discussed above. Furthermore, they can stimulate all other transition enabling developments, since there are interactions between them.

The Rijksrederij will need a multidisciplinary network of actors since they cannot develop and operate a climate neutral fleet by themselves. They will need to find or codevelop reliable, affordable and sustainable solutions for their entire fleet and make a clear transition plan, together with their network. This will build trust and a sustainable mindset in the transition for both their own organization and their clients. Regulatory developments will also be needed for climate neutral operation of the Rijksrederij.

**What are the transition enablers that can be created by a launching customer and specifically their pilot projects?**

Transition theories conceptualize niches, which can be established by launching customers, as the seeds for systemic change since they form a safe place for developing radically different 'ways of doing'. They enable learning processes, the articulation and adjustments of expectations and visions and the building of social networks that will lead to stable designs, expanding social networks and a growing acceptation of the new visions.

The interview analysis concludes that pilot project creates an incentive to all interdependent actors in the shipping cluster to cooperate and co-develop climate neutral sailing. The initial demand for climate neutral technology may loosen the interdependency barrier, reduce uncertainties and reduce some of the commercial infeasibility. It will create an opportunity for learning processes based on doing, using and interacting which can lead to a practice-based innovation cycle of evaluating, redesigning and testing. This mode of innovation is considered to be crucial, as it aligns with the innovation process of low quantity products. Pilot projects can thereby clarify which energy carrier and technology will be affordable, reliable and sustainable and improve these dimensions. Their impact will be the most significant for the pilot vessel type and operational area but can have a knock-on effect on larger parts of the cluster.
Pilot projects can also stimulate regulatory change since they will create a demand for regulations that allow climate neutral operations and policy that supports climate neutral development. A pilot will encounter all the existing regulatory barriers and thereby expose which changes are necessary. The design of the pilot vessel can also help to develop new regulations by serving as a baseline on which new regulations can be build.
Pilots can impact both the mindset and market and user practices when they demonstrate a climate neutral alternative that is operationally feasible. It can build trust in the new technologies and inspire others to start making contributions to the energy transition. Furthermore, the knowledge development of a pilot can enable other follow-up projects and make a scale-ups manageable.

It can be concluded from the case studies that launching customers can significantly reduce the marginal abatement costs by which they enable other actors to make a transition and reduce emissions. The available data was limited but it is concluded that the CAPEX of climate neutral sailing can be very well be reduced by over 20%. Furthermore, bunker and even production infrastructure can be developed and build when a launching customer creates a substantial and stable demand for an energy carrier. This could in theory make the OPEX of many climate neutral sailing practices lower than that of sailing on diesel. There are however, at the moment, no examples of where this has happened in practice.
The MAC for the vessel of the Rijksrederij is expected to be around €380 for a vessel lifetime of 25 years. Note that the MAC varies between €100 and €700 for the variety in vessels. A MAC of €380 is infeasible for a commercial party, which leads explains the scarcity of launching customers. It is expected that launching customers can reduce this MAC value by over 50% in the coming decade. For some vessel types and operations the reduction will be even higher. The Rijksrederij could thus lower the MAC which will enable many other actors to make a transition, by which enormous emission reductions are possible.
An organization with a similar favorable position for launching customership was not found during this thesis, especially considering the substantial size of the Rijksrederij fleet. If the Rijksrederij does not take on this position it is likely that the MAC for a certain area and vessel will remain at infeasible levels for multiple years longer. A climate neutral cluster will then also be multiple years further in the future, while this is already multiple decades away due to the lifetime of vessels and high costs of a retrofit. This illustrates how significant the transition enabling effect a launching customers as the Rijksrederij can be.
Case studies also concluded that launching customers can improve TRL levels to 9 over the course of multiple projects. This takes away uncertainties that could stimulate investments. It will also reduce regulatory and costs barriers. Furthermore, they proved that they can indeed be very successful in developing new climate neutral shipping practices, as was mentioned by interviewees and literature.

The Rijksrederij can use pilot projects to prove and further develop the climate neutral shipping practices that will be required for their transition. This can deliver a lot of valuable knowledge and experience, which will make the following steps in their transition manageable. An advantage for the Rijksrederij is that they do not have to compete with other actors and make a profit, which is difficult, if not impossible with an innovative pilot project. Another advantage is that they can spread out the pilot costs as innovation costs over all the follow-up projects, which will be the transition of their entire fleet. Furthermore, all their vessels operate relatively locally a transition if relatively feasible for many of these vessel types. A disadvantage is that they are not able to select their partners for large projects since they are bound by governmental procurement rules which can make long-term close cooperation whit a limited group of actors possible.

# Chapter 8

# Recommendations

This section will provide recommendations for further research. Recommendations for the Rijksrederij have already been provided in previous sections, so these will not be repeated here.

The interviews were conducted with a limited amount of participants and the case studies with a limited amount of projects, as a result the difference in significance of the barriers cannot be fully justified. With a larger set of interviewees and case studies findings about the transition barriers, enablers and pilot development trajectory, management and yield can be statistically substantiated. More insights could also be created by distributing a survey with the best-worst method developed by (Razaei, 2020). This was also originally the plan for this thesis but their was no confidence that enough relevant participants could be found. It is therefore recommended that a similar research with a larger data set is conducted.

The uncertainty in which energy carrier and technology will be used by a certain vessel, and what the prices and regulations will be is currently a significant and complex barrier. Solving it is depending on the direction of reorientation of the regime, the policies and regulations from authorities, supply and demand but also the developments that are being achieved in niches. Given the significance and complexity of this barrier it is recommended that research is conducted that aims to identify what the dynamics behind this uncertainty are and what is needed to make the choice of energy carrier less uncertain.

Given the interdependency between actors in the cluster and the barriers for increasing pressure from the landscape by hard regulations it would be interesting to research what is needed to stimulate the actors to join or even establish consortia. A consortium, that includes customers, classification societies and regulatory bodies, seems to be a good method to stimulate this reorientation, as was discussed in the discussion. It can also be used to stimulate the dialog between customer and shipowners about the costs of a climate neutral service, which can lead to climate neutral business cases, or perhaps even green corridors.

This thesis touched upon the difficulties of implementing regulatory changes while maintaining a level playing field multiple times, especially for the global playing field. There are however also parts of the shipping cluster that operate on a national or even smaller playing field. The Dutch government could already implement hard regulations for these parts of the cluster, and soft regulations for the rest. However, this will require both knowledge and interest from the Dutch government, which appears to be lacking at the moment. Research into what hard and soft measures could already be taken for the different parts of the cluster would be valuable for the transition.

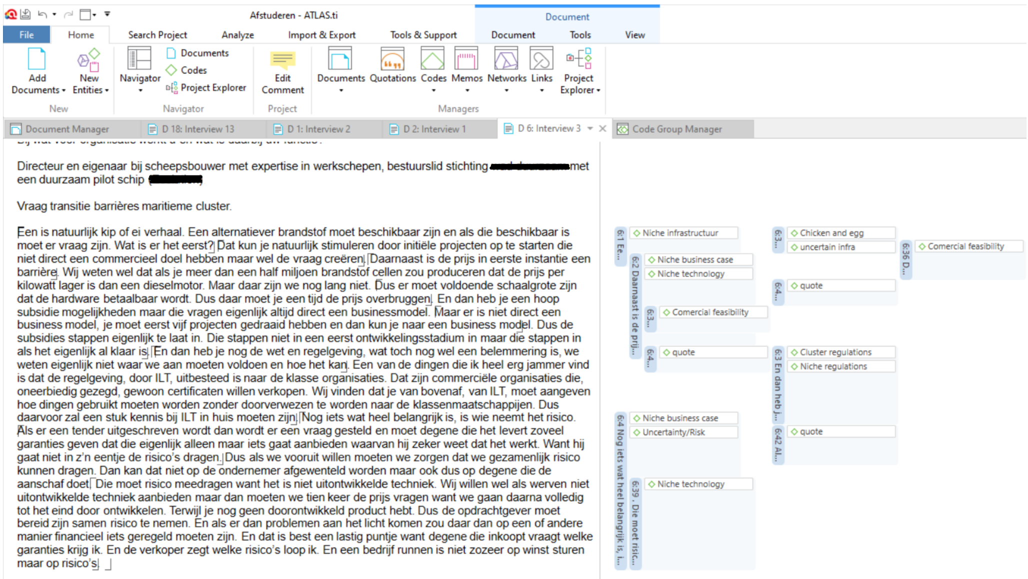
The method of assessing transition enablers by calculating the reduction of MAC appears to be the most accurate way of predicting scenarios for the shipping energy transition, as was discussed in the discussion. However, data for such scenarios appears to be scarce at the moment. It would be interesting to study what customers are willing to pay for a climate neutral service. Research into the current MAC for multiple ship types, energy carrier, cost scenarios would give insight into the current stage of the transition and possibilities for certain vessel types. If this is combined with research into the adoption-MAC curves, as presented in figure 6.3, a relatively reliable adoption curve can be estimated for multiple scenarios, instead of an imaginary one as presented in figure 6.2. This could substantiate the hard and soft regulations that bring a full transition forward.

# Chapter 9

# Appendixes

## 9.1 Appendix I: Atlas.ti method for explorative interviews

Figure 9.1 is a print screen that serves as an example of the interview analysis. After the thirteen interviews audio recordings were used for transcription. The interviews contained approximately 3500 words on average. All interviews where then uploaded into Atlas.ti for a qualitative analysis. The different subjects in the interviews each received a code, as can be seen in figure 9.1. Examples of these codes are ’cluster infrastructure’, ’niche mindset’ or ’uncertainty/risk’. Cluster infrastructure means that the infrastructure of the cluster is described, niche mindset means that the mindset in the niche is described and uncertainty/risk means that a mechanism concerning uncertainty or risks is discussed. A total of 41 codes were used to code all the different subjects of the interview. However, after an initial analysis is was found that multiple codes could be placed under one theme such as interdependency in the cluster, commercial feasibility of climate neutral sailing or uncertainty in the transition path. When a code is selected in Atlas.ti all sections that were given that code become visible. This was a very effective function for combining the knowledge provided in different interviews into an in-depth description of that subject.



Directeur en eigenaar bij scheepsbouwer met expertise in werkschepen, bestuurslid stichting [redacted] met een duurzaam pilot schip [redacted]

Vraag transitie barrières maritieme cluster.

Een is natuurlijk kip of ei verhaal. Een alternatiever brandstof moet beschikbaar zijn en als die beschikbaar is moet er vraag zijn. Wat is er het eerst? Dat kun je natuurlijk stimuleren door initiële projecten op te starten die niet direct een commercieel doel hebben maar wel de vraag creëren. Daarnaast is de prijs in eerste instantie een barrière. Wij weten wel dat als je meer dan een half miljoen brandstof cellen zou produceren dat de prijs per kilowatt lager is dan een dieselmotor. Maar daar zijn we nog lang niet. Dus er moet voldoende schaalgrote zijn dat de hardware betaalbaar wordt. Dus daar moet je een tijd de prijs overbruggen. En dan heb je een hoop subsidie mogelijkheden maar die vragen eigenlijk altijd direct een businessmodel. Maar er is niet direct een business model, je moet eerst vijf projecten gedraaid hebben en dan kun je naar een business model. Dus de subsidies stappen eigenlijk te laat in. Die stappen niet in een eerst ontwikkelingsstadium in maar die stappen in als het eigenlijk al klaar is. En dan heb je nog de wet en regelgeving, wat toch nog wel een belemmering is, we weten eigenlijk niet waar we aan moeten voldoen en hoe het kan. Een van de dingen die ik heel erg jammer vind is dat de regelgeving, door ILT, uitbesteed is naar de klasse organisaties. Dat zijn commerciële organisaties die, oneerbiedig gezegd, gewoon certificaten willen verkopen. Wij vinden dat je van bovenaf, van ILT, moet aangeven hoe dingen gebruikt moeten worden zonder doorverwezen te worden naar de klassenmaatschappijen. Dus daarvoor zal een stuk kennis bij ILT in huis moeten zijn. Nog iets wat heel belangrijk is, is wie neemt het risico. Als er een tender uitgeschreven wordt dan wordt er een vraag gesteld en moet degene die het levert zoveel garanties geven dat die eigenlijk alleen maar iets gaat aanbieden waarvan hij zeker weet dat het werkt. Want hij gaat niet in z’n eentje de risico’s dragen. Dus als we vooruit willen moeten we zorgen dat we gezamenlijk risico kunnen dragen. Dan kan dat niet op de ondernemer afgewenteld worden maar ook dus op degene die de aanschaf doet. Die moet risico meedragen want het is niet uitontwikkelde techniek. Wij willen wel als werven niet uitontwikkelde techniek aanbieden maar dan moeten we tien keer de prijs vragen want we gaan daarna volledig tot het eind door ontwikkelen. Terwijl je nog geen doorontwikkeld product hebt. Dus de opdrachtgever moet bereid zijn samen risico te nemen. En als er dan problemen aan het licht komen zou daar dan op een of andere manier financieel iets geregeld moeten zijn. En dat is best een lastig puntje want degene die inkoopt vraagt welke garanties krijg ik. En de verkoper zegt welke risico’s loop ik. En een bedrijf runnen is niet zozeer op winst sturen maar op risico’s.

Figure 9.1: Print screen of Atlas.ti interview analysis

## 9.2 Appendix II: Information Letter

**PARTICIPANT INFORMATION LETTER**

**Leadership in the maritime energy transition; what the Rijksrederij can contribute**

20-08-2020

Dear Sir / Madam,

You have been asked to participate in a study on the Dutch maritime energy transition. In this letter you will find information about the research. Please contact Louis Stolper if you have any questions, contact information is listed at the bottom of this letter.

**Background of the research**

In the Dutch Green Deal on Maritime and Inland Shipping and Ports it was agreed that the Rijksrederij will act as a launching customer of climate neutral sailing and thereby stimulate the Dutch maritime energy transition. The Rijksrederij will require knowledge on the transition pathway, barriers and chances to understand how they can be successful in their own transition and create the largest possible stimulus for the rest of the Dutch maritime sector.

**Purpose of the research**

This research tries to identify and describe the elements that play a role in the Dutch maritime energy transition to obtain a holistic overview, which will be used to understand the role the Rijksrederij can play. This will help the Rijksrederij with optimizing their transition plans and understanding which value they can create for the environment and the sector as a whole.

**Benefits and risks of participating**

As a participant you can contribute to the energy transition by sharing your knowledge and experiences. There is also a chance to learn more about the energy transition yourself in the discussion. I see no risks in participating in this research.

**What does participation in the research involve?**

This part of the research will consist of a small number of interviews via Microsoft teams video calling to test and further develop the knowledge on the energy transition that was obtained in a literature study. It will be a semi-structured interview so there will be some questions but there is also room for discussion. The audio and video of the interview will be recorded and transcribed. You are free to turn off your video during the interview, in that case only audio is recorded. The transcription will exclude any personal information, will only be used for the research and stored in a TU Delft repository.

**Procedures for withdrawal from the study**

Your cooperation in this research is voluntary. If you give your consent to this research, you have the freedom at all times (also during the interview) to come back on this decision. You do not have to give an explanation for your decision. You can do this by contacting Louis Stolper via L.C.Stolper@student.tudelft.nl

**Confidentiality of data**

This investigation requires that the following personal data are collected and used: name and email address. To safeguard and maintain confidentiality of your personal information, necessary security steps will be taken. Your data will be stored in a secure storage environment at TU Delft. All data will be processed confidentially and stored using a participant number only. Data will only be accessible for Louis Stolper, Jurrit Bergsma (PhD candidate TU Delft and daily supervisor of this research) and Jeroen Pruyn (Associate Professor TU Delft and faculty supervisor for this research).

The informed consent form will be stored on paper in a separate and secure location. This way all your details remain confidential. For the research you will be given a participant number to identify which data comes from you. Only the study team can know which participant number you have. Your participant number, name or email address will never be shared on publications (master thesis report, scientific publications, etc.) about the research. However, you organization type and place in the maritime sector (climate neutral niche, established shipowner, regulating authority, etc.) can be linked to your answers and published. Also your function within this type of organization can be mentioned in the research deliverables.

The results might be published in future scientific publications.

**Contact Information**

If you have any complaints regarding confidentiality of your data, you can contact the TU Delft Data Protection Officer (Erik van Leeuwen) via privacy-tud@tudelft.nl.

On behalf of the researcher, thank you in advance for your possible cooperation.

Louis Stolper

L.C.Stolper@student.tudelft.nl

## 9.3 Appendix III Informed consent form

*Q1.*
I have read and understood the Infromation Letter dated 20-08-2020, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.

Yes No
● ○

*Q2.* I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

Yes No
● ○

*Q3.*
I understand that taking part in this study involves that the audio and video of the interview is recorded, transcriped and anonymised but that I am free to turn off my video during the interview at any time.

Yes No
● ○

*Q4.*
I understand that information I provide will be used for a master thesis and possibly a journal paper.

Yes No
● ○

*Q5.* I understand that personal information collected about me that can identify me, such as my name, company name or email adres, will not be shared beyond the study team.

Yes No
● ○

*Q6.*
I give permission for the anonymised transcript of the interview to be archived in the TU Delft data repository so it can be used for future research and learning.

Yes No
● ○

*Q7.* I give permission to share and publish information about my organization type and place in the maritime sector (e.g. climate neutral niche, established shipowner, regulating authority, etcetera) and my function within this organization.

Yes No
● ○

*Q8.* Name:

Name

*Q9.* Date:

date

*Q10.* Please sign here:

×

clear

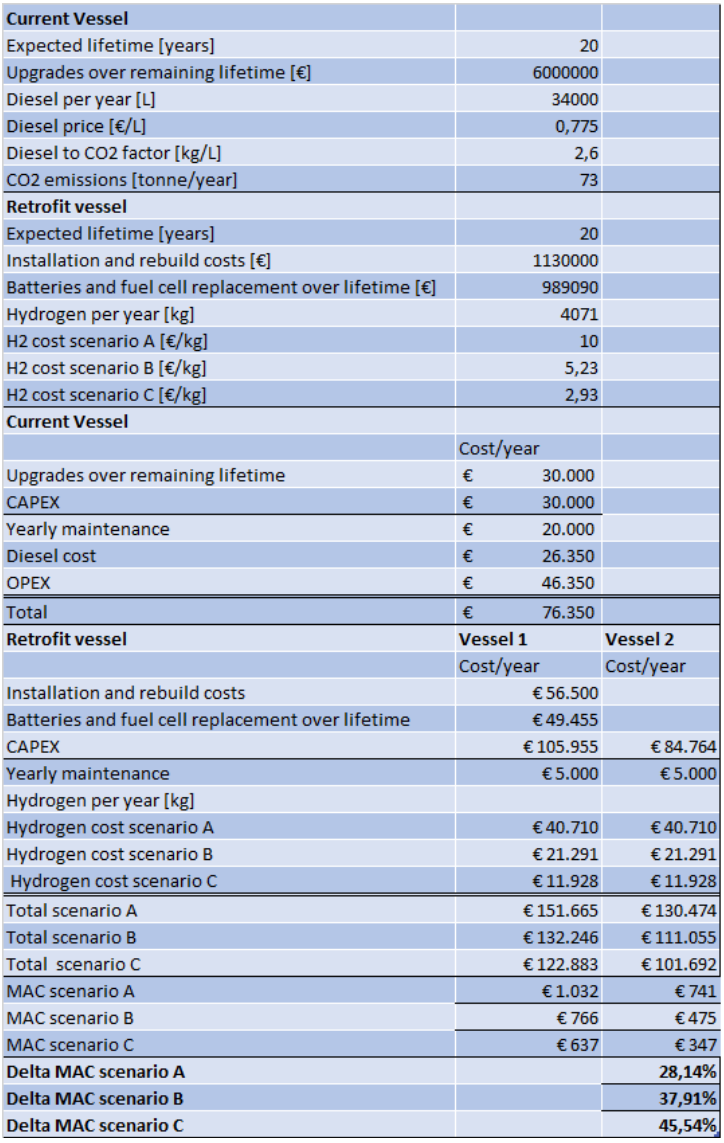
**Location Data**

**Location:** (51.995895385742, 4.3553009033203)

**Source:** GeoIP Estimation

## 9.4 Appendix IV: Delta MAC calculation for Krukel

Figure 9.2 presents an overview of the calculations for the reduction in MAC between the retrofit of a first and second Waddenunit. This calculation is based on similar calculations for shrimp cutters, tour boats and recreational vessels in Lauwersoog and the technical feasibility study of the Krukel. These reports supplied the data for used diesel per year, diesel to CO2 factor, hydrogen price scenarios, installation and rebuild costs and the costs for the replacement of batteries and fuel cells over the lifetime of the vessel. The estimated lifetime for a fuel cell is 7 years and for a battery is 10 years, which means a battery has to be replaced on time and a fuel cell two times. The total cost were calculated by adding the OPEX and CAPEX for the different scenarios. The MAC was then calculated by the difference between the yearly costs of sailing on hydrogen versus diesel and dividing this by the reduction in CO2 emissions. The delta MAC was calculated by taking the difference between the MAC for the first and second vessel, this does not include a reduction of hydrogen price between these two vessels.



| **Current Vessel** | | |
|---|---|---|
| Expected lifetime [years] | 20 | |
| Upgrades over remaining lifetime [€] | 6000000 | |
| Diesel per year [L] | 34000 | |
| Diesel price [€/L] | 0,775 | |
| Diesel to CO2 factor [kg/L] | 2,6 | |
| CO2 emissions [tonne/year] | 73 | |
| **Retrofit vessel** | | |
| Expected lifetime [years] | 20 | |
| Installation and rebuild costs [€] | 1130000 | |
| Batteries and fuel cell replacement over lifetime [€] | 989090 | |
| Hydrogen per year [kg] | 4071 | |
| H2 cost scenario A [€/kg] | 10 | |
| H2 cost scenario B [€/kg] | 5,23 | |
| H2 cost scenario C [€/kg] | 2,93 | |
| **Current Vessel** | | |
| | Cost/year | |
| Upgrades over remaining lifetime | € 30.000 | |
| CAPEX | € 30.000 | |
| Yearly maintenance | € 20.000 | |
| Diesel cost | € 26.350 | |
| OPEX | € 46.350 | |
| Total | € 76.350 | |
| **Retrofit vessel** | **Vessel 1** | **Vessel 2** |
| | Cost/year | Cost/year |
| Installation and rebuild costs | € 56.500 | |
| Batteries and fuel cell replacement over lifetime | € 49.455 | |
| CAPEX | € 105.955 | € 84.764 |
| Yearly maintenance | € 5.000 | € 5.000 |
| Hydrogen per year [kg] | | |
| Hydrogen cost scenario A | € 40.710 | € 40.710 |
| Hydrogen cost scenario B | € 21.291 | € 21.291 |
| Hydrogen cost scenario C | € 11.928 | € 11.928 |
| Total scenario A | € 151.665 | € 130.474 |
| Total scenario B | € 132.246 | € 111.055 |
| Total scenario C | € 122.883 | € 101.692 |
| MAC scenario A | € 1.032 | € 741 |
| MAC scenario B | € 766 | € 475 |
| MAC scenario C | € 637 | € 347 |
| **Delta MAC scenario A** | | **28,14%** |
| **Delta MAC scenario B** | | **37,91%** |
| **Delta MAC scenario C** | | **45,54%** |

**Figure 9.2:** Overview of the Delta MAC calculation with three scenarios, scenario A is for the current hydrogen prize, scenario B for hydrogen made with own electrolyzer and net power and scenario C for hydrogen made with own electrolyzer and power from solar field

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