Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Economics and Management
Dept. of Industrial Economics and Technology Management

Sidsel Amtoft Nissen

Managing barriers in the compressed hydrogen supply chain within the maritime sector from an innovation ecosystem perspective

Master's thesis in Global Manufacturing Management
Supervisor: Luitzen De Boer
Co-supervisor: Xinlu Qiu
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Preface

This Master thesis is a part of the course IØ3911, Master Thesis in Strategic Purchasing Management for the Master of Science in Global Manufacturing Management at The Norwegian University of Science and Technology and the project is written by Sidsel Amtoft Nissen. The project is written in collaboration with TrønderEnergi, and the purpose of the thesis is to assess how actors within the compressed hydrogen supply chain can overcome the present barriers while staying aligned. A conceptual framework for managing will be developed as a guideline for the actors to obtain the required knowledge within this field. The conceptual framework will have its outset in innovation ecosystem theory. A discussion will take place on whether the conceptual framework is applicable for its purpose.

I would like to express my gratitude for the valuable feedback and guidance to Luitzen de Boer, professor at the Department of Industrial Economics and Technology Management at NTNU, and to Xinlu Qiu, researcher at the Department of Industrial Economics and Technology Management. I would also like to thank my supervisors at TrønderEnergi for providing this interesting field of study and discussion of the thesis throughout the writing process. Lastly, I would like to thank the two employees at AQS and Ocean Hyway Cluster for participation in the case interviews, which were very valuable for writing this master thesis.

Abstract

This master thesis aims to investigate how actors within the compressed hydrogen supply chain can overcome the present barriers while staying aligned. The focus of the thesis is a potential future project where the actors seek to invest in compressed hydrogen as an alternative to maritime fossil fuels. The power company, TrønderEnergi, is interested in becoming a hydrogen manufacturer in Trøndelag and supplying hydrogen for maritime use. The shipping company, AQS, searches for alternatives to fossil fuels. AQS can, thus, become a potential customer of TrønderEnergi. For TrønderEnergi and AQS to raise the odds for project success the barriers along the entire supply chain must be managed.

The thesis will assess how TrønderEnergi and its co-actors perceive the same barriers, how they think the barriers can be solved, and whether they are aligned in their way of managing them. Three literature research have been conducted within the field of barriers in the hydrogen supply chain, designing a supply chain, and innovation ecosystem. The theory will act as the foundation to a developed conceptual framework whose purpose is to contribute to assessing the barriers, the ecosystem risk, and aligning the supply chain actors.

A qualitative case study was conducted with TrønderEnergi, AQS, and Ocean Hyway Cluster to understand how they perceive the same barriers, and how they see them being managed. The conducted interviews were used in the conceptual framework to gain a complete overview of the innovation project, and its risk concerning co-innovation and adoption chain actors, and to examine if the actors are aligned. It was discovered that there is consensus between what the three actors understand as barriers, and further, that they are aligned in how to manage them.

A discussion took place on the outcome of the applied conceptual framework and the concerned theories. The conclusion was that the conceptual framework showed potential to be applied in understanding issues and solutions from other perspectives than the focal firm's. However, it was not found to be adequate to the extent it is desired for TrønderEnergi. This will require an extension of the conceptual framework with support from other theories and frameworks.

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1 List of abbreviations

Abbreviation	Meaning
AQS	AQS - company name
CVC	Corporate venture capital
DF-ICE	Dual-fuel internal combustion engine
E-fuels	Electri-fuels
GHG	Green house gasses
LH2	Liquid hydrogen
LOHC	Liquid organic hydrogen carriers
LoZeC	Low- or zero carbon
MDO	Marine diesel oil
MGO	Marine gasoline oil
OHC	Ocean Hyway Cluster
PTX	Power to X
SME	Small medium enterprise
SMR	Small modular reactor
TE	TrønderEnergi
TSO	Transmission system operator

Table 1: Abbreviations and their respective meaning.

2 Introduction and background

2.1 Problem description

Society faces a new transition, the sustainable transition. Climate changes are inevitable, and we need to change the way we are operating in almost every sector and industry. Technologies must be rolled out incredibly fast to reach the Paris agreement. However, these technologies shall not only be key to freeing us from fossil fuels but also making us independent of fossil fuels from Russia. The last months have emphasized that the energy policy is also security policy. New promising technologies that can solve the big issues we are facing, stand in line to get the acceptance from the society and, thus, get the needed investments. What is not standing in line in the nearest future is a total integration of the promising technologies in the existing infrastructure. Our biggest industries and society are dependent on fossil fuels, and the fossil fuel technology is there. The infrastructure is there. Every supply chain actor is there. Last but not least, the market is there. This is, however, not the case with the alternatives to fossil fuels.

There are not many alternatives to fossil fuels, but one of them is hydrogen-based fuels also known as Power-to-X fuels. Electrification will prevail in all the sectors, which are possible to electrify. This requires expansions and upgrades to the existing electrical infrastructure. It is a huge task, but the area of electrification is not so unfamiliar since is a part of our everyday life and central to our society. However, where electrification of certain sectors or industries is not possible, such as the maritime sector and the heavy industry, other technologies have to be adopted.

Hydrogen-based fuels are expected to be one of the problem-solvers, since they can be produced from renewable energy and, thus, are zero-emissions fuels. A transition toward hydrogen-based fuels requires a revolution in the energy sector since it only exists in small-scale today. It requires hydrogen technology to mature. It requires the establishment of new infrastructure. It requires new supply chain actors and restructuring of the existing ones. It requires enormous investment from every partner. And last but far far from least, it requires a market. There are many challenges to be addressed but also many opportunities for the involved actors. The actors can innovate together, share knowledge, and develop an integrated solution. Actors within the maritime sector share the same vision of using hydrogen fuels as a substitute for fossil fuels, but the challenges and solutions they see are not necessarily the same. Furthermore, it is not necessarily the case that they share the same solution to the issue either. With different interests, collaborating actors must be aligned.

The three actors; TrønderEnergi, AQS AS, and Ocean Hyway Cluster are investigating how hydrogen can become a part of their business. TrønderEnergi is a manufacturer of hydrogen, AQS AS as a maritime fuel consumer, and Ocean Hyway Cluster represents all its members from the entire supply chain. They are positioned both upstream and downstream in the supply chain, and each of them has a different perspective on how hydrogen fuels can solve their issues and what the challenges and solutions are.

The master thesis will examine this area through a qualitative case study on how the different three actors understand the same barrier, how they think the barrier can be overcome, and whether or not they are aligned in their way of managing it. In combination with a case interview, a literature review will be conducted to understand the landscape of the hydrogen supply chain in the maritime sector. The focus of the literature review will be on four areas 1) an introduction to the supply chain for compressed hydrogen, 2) understanding the general barriers that exist in the supply chain for compressed hydrogen in the maritime sector, 3) understanding the fundamental components of establishing a supply chain, and 4) how innovation ecosystem analysis can contribute to the alignment of actors. A conceptual framework will be developed to understand how actors in a supply chain for compressed hydrogen act upon perceived barriers in relation to co-actors. TrønderEnergi will be the central actor, the focal firm, in the applied conceptual frameworks, and AQS and Ocean Hyway Cluster will be co-actors to TrønderEnergi. When the conceptual framework is applied by a focal firm, the focal firm shall gain a complete overview of the innovation projects, its risk in relation to co-innovation and adoption chain actors, and how alignment between the actors can be managed. The case interview and the conceptual framework will be used in combination to analyze how the actors perceive the future of the compressed hydrogen supply chain. Lastly, a discussion on how the conceptual framework and the theories apply to its purpose will take place.

2.2 Problem statement and research questions

So the overall problem statement for the thesis is: How do actors in the compressed hydrogen supply chain act upon perceived barriers in relation to co-actors?

The problem statement has been broken down into three research questions:

> RQ1: Identify general barriers in the supply chain for compressed hydrogen in the maritime sector.
>
> RQ2: Examine how one specific barrier is understood and managed by three actors within the supply chain of the maritime sector using the developed conceptual framework.
>
> RQ3: Discuss how the use of innovation ecosystem theory and the conceptual framework can be used by the supply chain actors to manage the specified barrier and to mitigate the risk of dis-alignment.

2.3 Structure of the master thesis

The master thesis will be structured into 8 chapters displayed in figure 1. The first chapter will give an introduction to the master thesis and the background for choosing this topic, present the problem statement, and finally describe the structure of the thesis.

Chapter 3 will describe the methodologies used in the master thesis. Chapter 4 will consist of four literature reviews in four areas, the purpose of it being to acquire knowledge about the hydrogen supply chain, barriers and drivers in the supply chain, important elements when designing a hydrogen supply chain, and theory on innovation ecosystems. The literature will be used as a foundation for the analysis and discussion chapter. Section 4.1 will give an introduction to the hydrogen supply chain, followed by section 4.2 describing the barriers and drivers in the hydrogen supply chain with have been identified in the academic literature. The section will partly answer RQ1: *Identify general barriers in the supply chain for compressed hydrogen in the maritime sector.* Section 4.3 consists of a review of articles concerning aspects that must be considered when building a hydrogen supply chain. The final section in the literature chapter in section 4.4 consists of literature on innovation ecosystems.

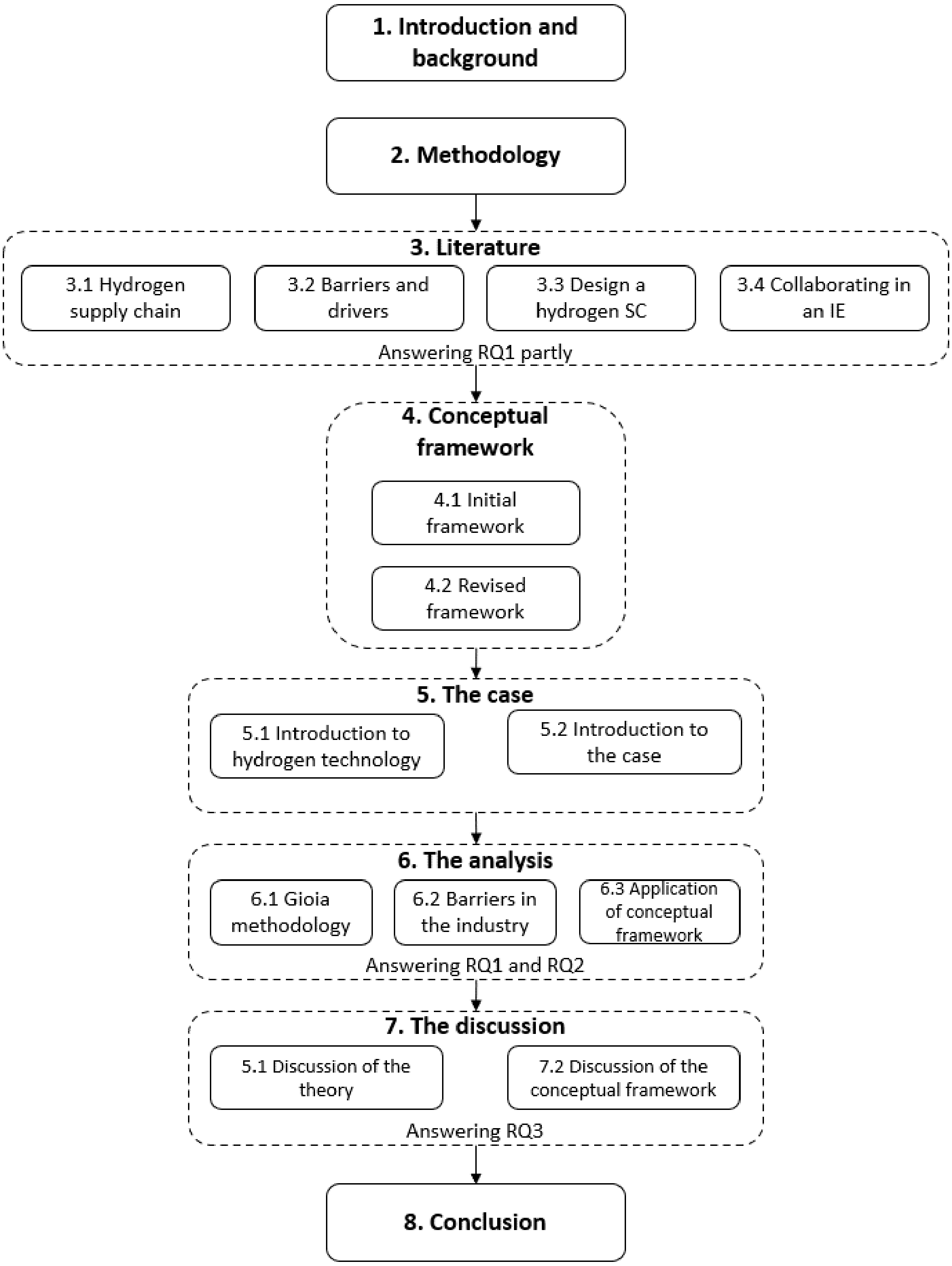

Figure 1: The structure of the thesis

In the next chapter 5 will present the initial conceptual framework for the project thesis by the undersigned. The conceptual framework will be revised by using the knowledge obtained in the literature chapter.

Chapter 6 will consist of an introduction to hydrogen technology and the different steps in the supply chain that are relevant to understanding the case, followed by an introduction to the case and the supply chain actors; TrønderEnergi, AQS AS, and Ocean Hyway Cluster.

In chapter, 7, the analysis will take place. It will be divided into three sections. In the first section 7.1, the analysis of the conducted interviews will be given using the Gioia methodology. By applying the Gioia methodology the data will be structured. Section 7.2 examines if there is a correlation between the barriers identified by the three actors and the barriers identified in the literature. It will furthermore answer RQ1 together with the findings from section 4.2. In the final section of the analysis chapter, section 7.3, the revised conceptual framework will be applied to the information from the conducted interview, and it will answer RQ2.

In chapter 8 the discussion will take place and RQ3 will be answered. The chapter will be divided into two sections. Section 8.1 will be based on the Gioia analysis from section 7.1, and a discussion, of how the theory can be applied, will take place. The findings in section 8.1 will be used in section 8.2 to discuss how the conceptual framework and the theory can be applied to the case.

Eventually, chapter 9 will conclude with the findings, and a section 9.1 on further work will examine which aspect that could be worked further on. References to chapters, sections, and literature are linked to the chapter if the reader clicks on the number, ex chapter 2.4 for going to the next section on limitations.

2.4 Limitations to the master thesis

The master thesis will assess how actors within the compressed hydrogen supply chain can overcome the present barriers while staying aligned. A conceptual framework for managing this will be developed as a guideline for the actors to get the required information within this field. The specific purpose of the conceptual framework is for the focal firm to get a comprehensive understanding of the innovation in relation to co-innovation and adoption chain risk, and how these can be managed to secure alignment. The conceptual framework is developed by the integration of different frameworks explained in section 5.2. It is believed that the frameworks in combination can contribute to giving the desired overview to assessing the barriers, ecosystem risk, and aligning the supply chain actors.

The main framework in the developed conceptual framework is the value blueprint by Adner (2012). Frameworks by M. Henderson and Clark (1990), Adner (2006), Budden and Murray (2019), and Andersen et al. (2018) will be integrated into the value blueprint, because it is evaluated that the value blueprint by Adner (2012) lack certain aspects. A discussion on the conceptual framework, its theories, and how it can be applied will takes place to verify it.

The conceptual framework touches on many different topics such as ecosystem identification, first-mover advantages, innovation types, and managing co-innovation risk, and a master thesis could be made on each of these topics. This thesis will, thus, be limited to examining one chosen barrier and one solution by using the conceptual framework as a guideline. A thorough application of the conceptual framework requires deep insight and knowledge from each of the companies. It is, thus, recommended that the actors apply the conceptual framework to make use of its full potential. The discussion will be limited to concern only how the conceptual framework and its theories are applicable for the actors to overcome barriers and stay aligned. There will be a focus on the co-innovation risk and adoption chain risk concerning the barrier in focus. Due to the early phase of the project which still is on the drawing board, there will not be a focus on the execution risk. Eventually, the conceptual framework will be evaluated and possible changes will be recommended.

3 Methodology

In this chapter the methodology of the case study will be presented. The specific methodology chosen is based on the book *Social Research Methods* by Bryman (2016). The following aspects will be covered in accordance with Brymans recommendations:

- Section 3.1 Literature review
- Section 3.2 Research strategy and design
- Section 3.3 Data sampling and collection
- Section 3.4 Data analysis
- Section 2.4 Limitations to the methodology

3.1 Literature review

To examine the barriers to the implementation of compressed hydrogen in the maritime sector a literature review has been conducted. The narrative approach has been selected because the systematic approach is too comprehensive and too time demanding for the scope of this master thesis. The topics have been selected in collaboration with supervisors, and literature is chosen based on their knowledge and literature search within these topics. Three search keys have been selected to find relevant literature. The first search key is ”hydrogen AND logistics AND barriers AND maritime” and has been chosen to find literature on logistic barriers in hydrogen for maritime use. This literature will be used in the analysis chapter 7.2 to examine if the interviewed actors identify the same barriers as the academic research.

The second search key is ”design AND supply chain AND green hydrogen AND maritime” and is chosen to get an understanding of how a hydrogen supply chain for maritime use can be established and which elements the researcher has extra focus at.

The third search key is ”establish AND innovation ecosystem” to get literature about establishing an innovation ecosystem. The search results are shown in table 2.

Topic	Search key	Literature
Barriers	hydrogen AND logistics AND barriers AND maritime	Sintef (2020) Bach et al. (2020) DNVGL (2021)
Supply chain Design	design AND supply chain AND green hydrogen AND maritime	Stöckl et al. (2021) Šťádlerová and Schütz (2021) M. Henderson and Clark (1990) Nalebuff and Brandenburger (1997)
Innovation Ecosystem	innovation ecosystem	Budden and Murray (2019) Adner (2006) Adner (2012)

Table 2: The chosen search keys and the selected literature.

3.2 Research strategy and design

Figure 2 gives an overview of the methodology. The red path shows which type of methodology has been chosen in this study. The path will be elaborated in the following sections.

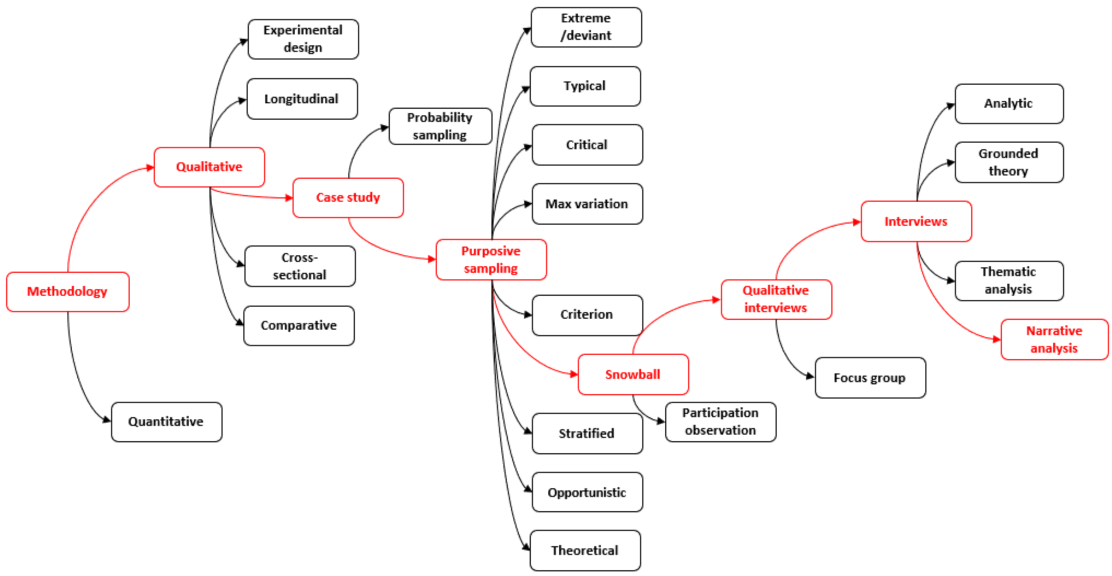

Figure 2: An overview of the methodology used in the master thesis

The research design of the study is a case study. A case study has been chosen because the objective of the thesis is to examine how a group of actors perceive the same project. The case is explained in chapter 6 and concerns actors that are interesting in investing in hydrogen. One actor from the supply side and one from the demand side. In a case study, the researchers try to conduct an in-depth examination of the case. This case study will examine how the actors understand the barriers, how they perceive their own as well as their co-actors roles, and how they think the barriers can be managed. To examine this area, a qualitative study will be performed. A qualitative study has been chosen to encourage the actors to elaborate on their sustainable strategy, how they see barriers in the supply chain, how they perceive the future of hydrogen, and which criteria must be present for them to start investing.

The semi-structured interview has been chosen as the qualitative interview. A semi-structured interview allows the researcher to ask the same questions to the participating actors and at the same time ask follow-up questions if an elaboration by the interviewee is called for. The fact that every participating actors get the same question makes it easier and potentially more valid to compare the different actors' answer. Being able to ask follow-up question creates room for the interviewee to elaborate on aspects that is in the interest of the interviewer.

If the master thesis project took place over an extended period, the longitudinal research design could have been interesting. The actors would then be followed throughout the project and interviewed for example a year later. This would reveal how the actors evolve their understanding of the barriers and how they manage them. It would also display changes in alignment and how each of them perceived the project. However, due to the limited scope of this thesis, the longitudinal research design was not chosen.

3.3 Data sampling and collection

The sample has been selected based on the criteria that all participants are upstream and downstream actors within the same supply chain of compressed hydrogen, and all participants are interested in using hydrogen as a maritime fuel. Three actors have been asked to participate in the interview and they have been chosen because they are related to a possible future project together with TrønderEnergi. TrønderEnergi has been selected as the focal company because the master thesis is written in collaboration with them. The other two actors are AQS AS and Ocean Hyway Cluster. In the thesis, the three actors are referred to as TE(TrønderEnergi), AQS, and OHC(Ocean Hyway Cluster). TE and AQS are both in the investigating phase of a project, where TE is looking into producing compressed hydrogen for the vessels owned by AQS. AQS has been chosen, as they are in the same supply chain as TrønderEnergi, but placed further downstream. OHC is the third actor, and they have been chosen because they are a cluster representing over 70 members in the maritime sector that are interested in hydrogen. OHC possesses an overview of the maritime hydrogen sector, enabling it to take the perspective of many different supply chain actors. The case concerns how TE and AQS perceive the same barriers and how they are aligned in their view, and OHC is chosen to add its members' perspectives to the case.

The data on the informants was collected by an employee at TrønderEnergi that communicated with AQS and Ocean Hyway Cluster. The communication was established via e-mail followed by a call-in for the interview. The interviews were performed through Teams and the recordings were saved in SharePoint. The interviews were transcribed from the recordings.

As mentioned, the interview was conducted as a semi-structured interview, as described in section 3.2. The semi-structured approach made it possible to get answers elaborate if the interviewer felt the need for it. The interview guide is attached in appendix B.

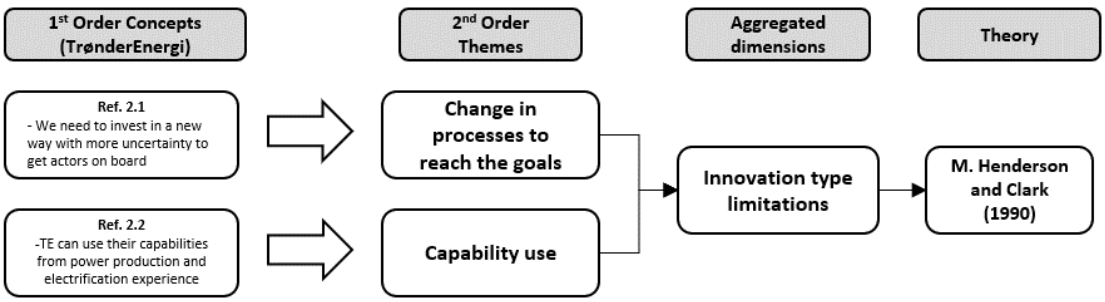

Figure 3: An example of an application of the Aggregated Dimension of Innovation type limitations

3.4 Data analysis

The data will be analyzed and structured by using the Gioia methodology by Gioia et al. (2013) shown in figure 3. The analysis process is divided into 3 parts; 1st Order Concepts, 2nd Order Themes, and Aggregate Dimensions. The 1st Order Concepts are phenomena the informant has observed. The concepts are derived from the interview and are true to the informant's terms. The 2nd Order Themes are the themes that can help explain the phenomena in the 1st Order Concept. The 2nd Order Themes, thus, answers the question "what is really going on?". In the analysis of the interviews many 1st Order Concepts are observed, and some of them have the same 2nd Order

Theme in common as can be seen in the middle column in figure 3 from an example made by Gioia et al. (2013).

To structure the concepts further the concepts are structured in a final theoretical dimension, the Aggregated Dimension. The Aggregated Dimension is determined by looking at the concepts from a wider perspective f.ex.by drawing on theoretical insights. The purpose of the Aggregated Dimension is to align the 2nd Order Theme with the theory. The three orders represent the building blocks for the data structure.

When the 2nd Order Themes and the Aggregate Dimension have been completed on all 1st Order Concepts a pattern will emerge. Several of the 1st and 2nd Orders will have the same Aggregated Dimension and the Gioia Methodology is a way of structuring the information flow from the informant and matching it with the relevant literature to compare the concepts with the theoretical knowledge. The determined Aggregated Dimensions should represent the concepts discovered in the chosen examined literature, but can also reveal new concepts that have not been discussed in the literature chapter. The Gioia methodology is useful in this master thesis because it allows structuring several interviews to make the data comparable and connects it to the theory.

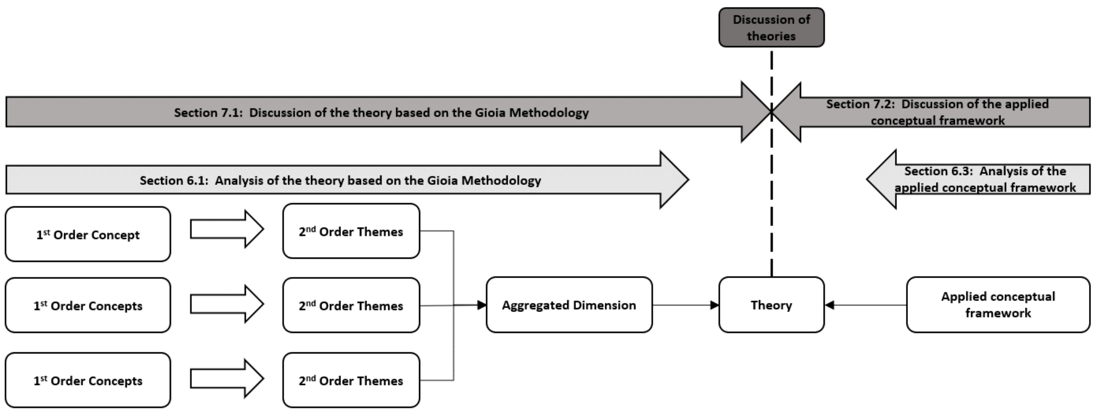

Figure 4: The figure displays the structure of the discussion.

Figure 36 illustrates how the discussion will take place. The three elements form the Gioia methodology; 1st Order Concepts, 2nd Order Themes, and Aggregated Dimensions are applied to discuss the theory. As an extra dimension, the developed conceptual framework from section 5.2 will be used in the discussion to assist in the discussion of how the theory can be applied to an actual case.

3.5 Limitations to the methodology

In qualitative interviews, it is possible to get an elaborate description of the topic. However, this does require that the questions are asked in a manner that precludes misunderstandings and undesirable associations. By choosing a semi-structured approach the interviewer has the possibility to elaborate on the questions, if the answers are not satisfying or if the answer creates a need for follow-up questions. It also makes it possible for the interviewer to change the sequence of questions from interview to interview.

The actors have been chosen by TrønderEnergi and are actors with whom TrønderEnergi already has had some collaboration. They can, thus, be biased, which can be reflected in their answers.

The literature has been selected through a narrative approach because a systematic approach would be too time demanding. The limitations, when choosing the narrative approach instead of the systemic, are that the problem statement is viewed from a self-elected perspective, and other perspectives and literature could have been relevant to examine.

In the formulation of the problem statement and research question, it was determined to focus on only one barrier in the analysis of the conceptual framework. A full comprehensive analysis of every barrier with the use of the conceptual framework exceeds the extent of this master thesis.

With the Gioia methodology, a data structure is determined through 1st Order Concepts, 2nd Order Themes, and Aggregated Dimensions. The 1st Order Concepts are phenomena observed by the informant and the concepts are true for the informant. However, the 2nd Order Themes are determined by the undersigned based on what the undersigned perceives as the theme of the concept. A different view on the concept could result in a different theme. This also applies the Aggregated Dimension that is determined by the undersigned by aligning the data with the theory. Other patterns could have been detected.

4 Literature

This chapter will present the literature used in the master thesis. Answering the problem statement requires knowledge of the hydrogen supply chain, barriers within the hydrogen supply chain, and collaboration in the ecosystem to get a solid theoretical foundation. This knowledge will be applied in the discussion chapter 8 assisted by the analysis of the case 7 and listed topics will be described in the following sections. See 1 for the structure of the thesis.

- **Section 4.1** An introduction to the hydrogen supply chain
- **Section 4.2** Barriers and drivers in the implementation of compressed hydrogen in the maritime sector
- **Section 4.3** Designing a hydrogen supply chain
- **Section 4.4** Collaborating in an innovation ecosystem

The first section 4.1 introduces and explains the hydrogen supply chain. Section 4.2 presents identified barriers and drivers that exist when implementing hydrogen in the maritime sector. The barriers and the insufficient supply chain have been a researched area in the latest years, and a sample of articles has been chosen to illustrate possible ways to design and build a hydrogen supply chain in section 4.3. Lastly, literature on collaborating in an innovation ecosystem is presented in section 4.4 to understand the opportunities and challenges that arises when stakeholders collaborate.

4.1 Supply chain for compressed green hydrogen

The hydrogen supply chain is a hot topic at the moment due to it being a central element in both solving the climate crisis and becoming independent of Russian gas. With this in mind, it is also very relevant that no supply chain exists for large-scale green hydrogen (Ratnakar et al., 2021, p. 24158). This means that there is a big opportunity in redesigning the current energy sector and developing optimal solutions and securing the integration of relevant actors and their processes and products for future use. Figure 5 displays a simple version of the supply chain for compressed hydrogen. Renewable energy is used to produce hydrogen from water. The hydrogen will be compressed and stored until it will be bunked onboard a vessel to be used as fuel. The customers who have rented the vessel will have their product transported with zero emissions with the use of hydrogen. A more detailed description of the supply chain and the technology is given in the case chapter 6.

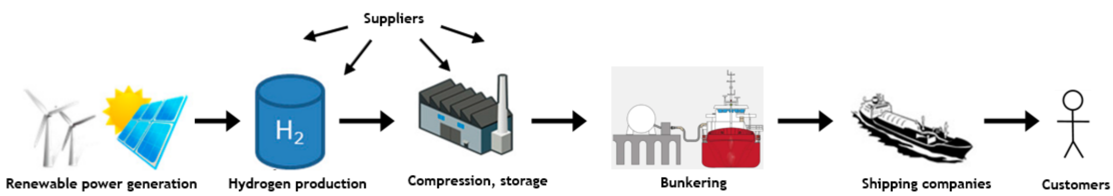

Figure 5: The main steps in the supply chain for compressed hydrogen for the maritime sector. Pictures by Ozawa et al. (2017) and TrelleBorg (2022).

As already mentioned a commercialized supply chain for hydrogen does not exist. This is not optimal when considering that solving the climate crisis and getting independence from Russian gas is urgent. However, this is also an opportunity for the supply chain actors to develop a chain, where all actors collaborate on an integrated solution. Instead of developing single units that have to work together, the integration of the supply chain components can be considered thoroughly in the designing of the components. When supply chain actors collaborate in developing products or processes by sharing knowledge and capabilities, they can make a product that no single firm could do on their own because they often lack capabilities(Adner, 2006). Furthermore, combining forces can lead to faster product and process development and lead to a solution that is better integrated into the society with better use of the local workforce and resources. However, if the collaboration between the actors is not optimal, it can also lead to delays and products that are far from ideal. To harvest the high-hanging fruits, the alignment of the supply chain actors is highly desirable. These aspects will be considered in the following three sections.

4.2 Barriers and drivers in the implementation of green hydrogen in the maritime sector

GL (2018) made a forecast on the global energy transition to 2050. They predict hydrogen will have a share of less than 2% as a shipping fuel mix by 2050. This is not the best outlook for hydrogen fuel enthusiasts but a lot has happened since 2018, especially in top politics. Hydrogen has become a geopolitical priority and countries are competing to be in front of the race CSIRO (2021). Change in the political winds is important to pave the way toward a hydrogen economy, and having national and regional politics in place is one of the most important factors to achieving faster technology development. This view is described by Sintef (2020) and Bach et al. (2020) where they mention support from the government as one of the main drivers toward a hydrogen economy. The following sections begin with a short description of the chosen articles, followed by a description of the main barriers identified in the supply chain for compressed hydrogen in the maritime sector (section 4.2.1) and the identified drivers (section 4.2.2). See figure 1 for the structure of the thesis.

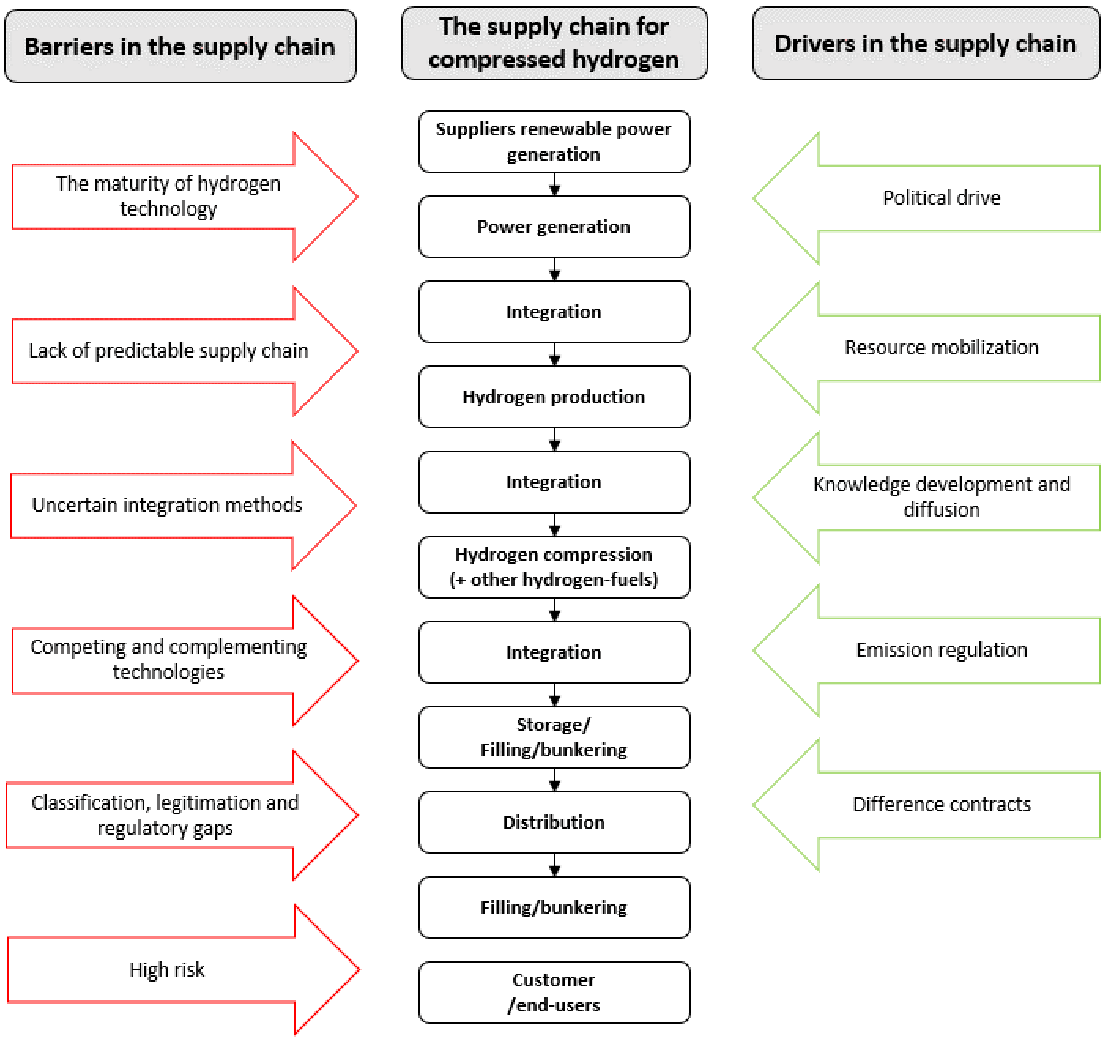

Figure 6: The main barriers and drivers in the supply chain of compressed hydrogen in the maritime sector

Implementing maritime battery-electric and hydrogen solutions: A technological innovation systems analysis by Bach et al. (2020).

The article by Bach et al. (2020) makes use of the technological innovation system (TIS) framework to examine the current status of the battery-electric and hydrogen solutions for the maritime industry. Bach et al. (2020) uses the TIS framework to map out the landscape in the two areas, examining the environmental benefits, the strengths, and the weaknesses when replacing fossil fuels with battery-electric and hydrogen fuels. The master thesis will focus on the TIS for hydrogen and the TIS for battery-electric will be described briefly. The function analysis of hydrogen assesses the following areas:

- Knowledge development and diffusion
- Influence of the direction of search
- Entrepreneurial experimentation
- Market formation
- Legitimation
- Resource mobilization
- Development of positive externalities

Large scale hydrogen production in Norway - possible transition pathways towards 2050. Sintef (2020)

The report by Sintef (2020) discusses how Norwegian hydrogen production can play a role in the sustainable energy transition towards 2050. The report describes how hydrogen production and deployment are influenced by market trends, socio-politics, and national regime developments. The report maps out the landscape for hydrogen production in Norway by examining ongoing initiatives and stakeholder perspectives. Furthermore, the report describes drivers and barriers within several areas such as production, maritime, transport, and industry. Next, the report gives a multilevel perspective on the scope for hydrogen in Norway's energy transition and final with possible transition pathways for hydrogen. This master thesis will focus on the perspective of hydrogen in the maritime sector. In the following sections, the drivers and the barriers will be described. The different drivers and barriers have been separated to make them easier to grasp, however, most of them are interrelated.

4.2.1 Identified barriers in the implementation of compressed hydrogen in the maritime sector

In figure 6 the barriers identified by Sintef (2020) and Bach et al. (2020) have been illustrated. Each barrier will be identified in the following.

The maturity of hydrogen technology
One of the main barriers and also a highly discussed topic is the maturity of hydrogen technology. Some companies claim their product is mature, and some have the opposite understanding. The technology readiness level(TRL) of the hydrogen technology differs from product to product. The technology for the alkaline electrolyzer is considered mature, whereas PEM is rated at level 6 on a scale of 9 (Pinsky et al., 2020). As the technology is not 100% mature, it requires more willingness for the investors to take risks. DNV (2021) has a different view on the maturity of hydrogen technology. They use the scale Categorization of new technology by IMO (IMO, 2013). The scale goes from 1 to 4, where 1 is a proven technology and 4 is a new or unproven technology. Even though

some technologies such as fuel cells and hydrogen storage tanks have been used in the transport sector, the hydrogen technology has not been applied to the maritime sector and tested in harsh marine conditions. IMO, thus, categorizes the hydrogen technology for maritime application as level 4, since it is unproven (DNV, 2021). The categorization of 4 imply requirements of extensive risk analyses which results in complex construction processes and higher financial demands leading to longer lead times for getting the respective hydrogen technology approved for maritime use (Bach et al., 2020).

Shipping companies are interested in hydrogen, however, the immaturity of the technology is a roadblock for them. Bach et al. (2020) state that the immaturity of the technology has triggered suppliers and ship-owners to criticize the rule of a 10-year operating commitment mandated by the Norwegian Public Roads Administration. This is a problem since the suppliers hesitate to issue a 10-years guarantee due to the immaturity of the technology (Bach et al., 2020).

Classification guidelines, legitimation and regulatory gaps
The maturity of hydrogen technology also influences the safety rules and classification guidelines. Hydrogen fuels require new infrastructure, equipment, bunkering stations, filling stations, pipelines, ships, production facilities, etc. Before being applied in different sectors and industries, classification guidelines need to be developed for the specific purpose to ensure the highest safety measures. At the beginning of 2022, the classification guidelines for fuel cell and fuel cell space will be released. However, IMO still has not started working on guidelines for storage of hydrogen (DNV, 2021). This creates uncertainty about the emerging hydrogen technology creating longer lead times and causing maritime actors to hesitate to invest (Bach et al., 2020).

Lack of predictable supply chain
According to coastal high-speed passenger ferries operators (Bach et al., 2020) they see the insufficient supply chain as the main barrier. They mention for example the absence of bunker infrastructure, infrequent fuel availability, and high fuel prices (Bach et al., 2020). However, they believe that hydrogen technology has a big potential when it is further developed and regulations are in place.

Supply chain bunkering facilities
Even though the risk can be mitigated with the dual-fuel engines (Solutions, 2022a), it is crucial that there are bunkering facilities along the coast.

Competing and complementing technologies
Hydrogen has often been viewed as an alternative to batteries, however currently batteries will fit most optimal for ships that sail shorter distances, whereas hydrogen is better for longer distances. In the article by Bach et al. (2020) the pros and cons of hydrogen and batteries are discussed. Even though the consensus is that battery-electric is not an adequate Low and zero-carbon technology (LoZeC), ship-owners and shipyards are to some extent unwilling to test other technologies such as hydrogen due to the financial risk and lack of resources. However, hydrogen is also in competition with itself. Where the hydrogen production manufacturer competes with batteries and other storing options, the shipping company has to decide in which form they want to utilize hydrogen. Hydrogen can be used as a fuel as is, but it can also work as a carrier by converting it into other E-fuels such as methanol or ammonia. The combustion engine manufacturers are, therefore, designing so-called dual-fuel engines (Solutions, 2022a). The dual-fuel engines can run on zero-emissions or net-zero fuels such as hydrogen, ammonia, and methanol but also use marine gasoline oil(MGO) and marine diesel oil(MDO), giving the ship-owners more flexibility and lessening the risk of a

lock-in scenario.

The LoZeC technologies are competing, however, they are also complementing each other, and the development of battery-electric, biofuels, and blue hydrogen technology can also be an advantage for green hydrogen (Bach et al., 2020). The LoZeC technologies have many similarities and they share some of the central components in the supply chain. For example, they share the need for the installation of more renewable power, new gas infrastructure, and new regulations.

High risk
It imposes a high risk on shipping companies to invest in the first generation of ships running on hydrogen. The contracts of public tendered ships usually run 10 years and the lifespan of most ships is 30-40 years. This leads to shipping companies being afraid of ending in a locked-in situation with a ship that uses a zero-emission fuel that has been out-competed (Sintef, 2020). Bach et al. (2020) mentions public procurement as a means to minimize the lock-in effects by designing specific requirements that mitigate the risk of this.

4.2.2 Identified drivers in the implementation of compressed hydrogen in the maritime sector

The previous sections describe a score of barriers that are identified in the maritime sector. How do we manage these barriers? Strategies have been devised to minimize some of the barriers, but only time will show if the barriers can be fully mitigated. In figure 6 the identified drivers to manage the barriers by Sintef (2020) and Bach et al. (2020) are illustrated. Each driver will be identified in the following.

Political drive
Sintef (2020) clearly states that the main drivers towards implementing hydrogen in the maritime sector are political engagement and involvement. Sintef (2020) mentions national climate targets for the maritime sector, a national plan for green shipping, substantial incentives, CO2 taxes, and green public procurement.

Difference contracts
One of the important driving mechanisms is the state guarantee that covers the higher operating costs when changing to hydrogen fuel. This is also referred to as difference contracts (Ukeblad, 2022). This is of the highest importance since hydrogen has to match the cost of conventional fuels (Bach et al., 2020).

Emissions regulations
According to coastal high-speed passenger ferries, strict regulations on emissions (Bach et al., 2020) have urged them and made them more willing to change to hydrogen fuels. An example is the Tier 3 requirements that will come into force in 2025. To continue operating in the Norwegian Fjords, shipping companies have to invest in LoZeC technology that complies with Tier 3 requirements. New regulations create a need for equipment that complies with the regulation, thereby generating growth in the LoZeC market.

Resource mobilization and development of positive externalities
The last aspect to consider is the public and private investment in hydrogen (Bach et al., 2020). In the previous century, massive investments have been made in the fossil fuel market, and there is still an incredible amount invested in it (Zetland, 2022). In the future investments must move to

LoZeC technologies. The actors and regions of the fossil era potentially look into a not so glorious future. This can trigger huge changes in geopolitics. Some companies will, thus, have a bigger incentive to mobilize resources than others. Furthermore, it is also worth considering the potential spillovers. When the first actors start investing, it creates possibilities for the development of positive externalizes and clusters. Latecomers can enter without taking too much risk and instead enjoy free-riding in terms of technology development and increased legitimacy (Bach et al., 2020). Bach et al. (2020) describe the Norwegian interpretation that Norwegian companies have the knowledge and capabilities to start a new energy adventure. The Norwegian Government can with political incentives initiate extra development, that will result in the development of positive externalizes and later make new companies enjoy the free-riding.

4.2.3 Part conclusion

The literature was chosen to give an overview of the barriers that have been identified in the hydrogen supply chain, and in summary, it points to immature technology, a lack of predictable supply chain, and uncertain integration methods. Furthermore, the different hydrogen fuels are both competing and complementing each other to gain more market share for each technology. The last barrier is the regulatory gaps. Altogether it results in a high risk in investing in the compressed hydrogen. Important drivers for the hydrogen supply chain to get established must be implemented by government support. Resource mobilization and knowledge diffusion of the hydrogen technologies will also be important drivers. Understanding which barriers are present in the supply chain and how they can be managed at a higher pace will be helpful to the actors trying to overcome the barriers. The next section covers the topic of designing an optimal supply of hydrogen. The focus will be on designing a hydrogen supply chain with the existing barriers in mind as well as general principles for designing a supply chain.

4.3 Designing a hydrogen supply chain

The theory that has been examined so far concerns the hydrogen technology and the barriers and drivers that exist in the maritime sector towards implementing hydrogen as a maritime fuel. One of the reasons why there are many barriers present to implementing hydrogen as a fuel is due to the non-existing hydrogen supply chain. This chapter will consist of the article by Stöckl et al. (2021) on the design of a hydrogen supply chain with a focus on the distribution. The customers are land transport and, thus, do not have the maritime sector as a target group, however, many of the considerations when designing the hydrogen supply chain for land transport are also relevant when designing the maritime hydrogen supply chain. Following is an article on important aspects to consider in building a supply chain in general. The article by M. Henderson and Clark (1990) concerns what established firms must consider when making radical innovations. Figure 1 is recommended to see the structure of the thesis.

Optimal supply chains and power sector benefits of green hydrogen by Stöckl et al. (2021) As previously stated, there does not exist a well-functioning supply chain for green hydrogen. This is a challenge, however, it is also an opportunity to establish and design a supply chain that is integrated with the different sectors and industries. The article "Optimal supply chains and power sector benefits of green hydrogen" by Stöckl et al. (2021) examine the aspects of how hydrogen-based electrification with the already established power system. Hydrogen makes it possible to indirectly use renewable power with the power of gas transformation. However, how the hydrogen supply chain is going to be realized and designed is still a question. One of the biggest advantages of hydrogen is, that it is stored and used when needed, which increases the temporal flexibility of the power sector (Stöckl et al., 2021).

This fits well into the well-known challenges with renewable power that has to be used when the sun shines, and the wind blows. Using hydrogen as storage increases the flexibility of the power system, but it is not necessary the most energy-efficient method due to cost, low energy efficiency, and adding more conversion steps. Stöckl et al. (2021) addressed how green hydrogen and the power sector can be integrated with a focus on flexibility and energy efficiency in four future hydrogen supply chains in Germany. The article concludes that their study can med applied to other geographical sectors. However, the benefits of more flexible hydrogen supply chains are substantially lower in a geographical setting with a large renewable energy source such as hydro power, as the case with Norway,

Parameters that impact the model:

- The hydrogen demand
- Availability and cost of technologies
- The hourly time series of electricity demand
- Renewable capacity factors

The main decisions variable:

- Power capacity
- Hydrogen capacity
- The hourly use

The optimization of the model is pointed towards constraints that include. With these inputs the model will determine a long-run first-best equilibrium benchmark for a friction less market Stöckl et al. (2021).

Constraints:

- The market balance for electricity and hydrogen where supply and demand are equated on an hourly basis
- Capacity limits for generation and investment
- The minimum share of renewable energy

The model outputs are:

- System cost
- Optimal capacities
- Their hourly use

To determine the optimal solution it considers above mention considerations, furthermore, it mentions that tariffs, taxes, operational safety, and public acceptance should be included and considered, too. Based on the above-listed information as available information on hydrogen supply and demand, determines whether small- or large-scale is most optimal together with GH2, LH2, and LOCH are preferred. The article is useful due to its perspective on the trade-off between energy efficiency, and flexibility. All this influences how the optimal hydrogen supply chain shall be built. The article concludes that the energy markets and policymakers should design the tariffs and taxes in such a way that it does not distort the prices in all of the hydrogen supply chain steps, but still make it possible to allocate the present benefits between hydrogen and electricity consumers(Stöckl et al., 2021, p. 12).

Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms by M. Henderson and Clark (1990)

The traditional categorization of innovation says that it either happens incrementally or radically. However, M. Henderson and Clark (1990) believes this is misleading and that taking this perspective can have grave consequences for the industry actors. They define two additional types of innovation; architectural innovation and modular innovation, as shown in figure 7. The definition of architectural innovation says *"Architectural innovation occurs when new products or services use existing technology to create new markets and/or new consumers that did not purchase that item before"*Pressbooks (2020). There are of course overlaps between the four types of innovation, however, the focus in the article by M. Henderson and Clark (1990) is architectural innovation.

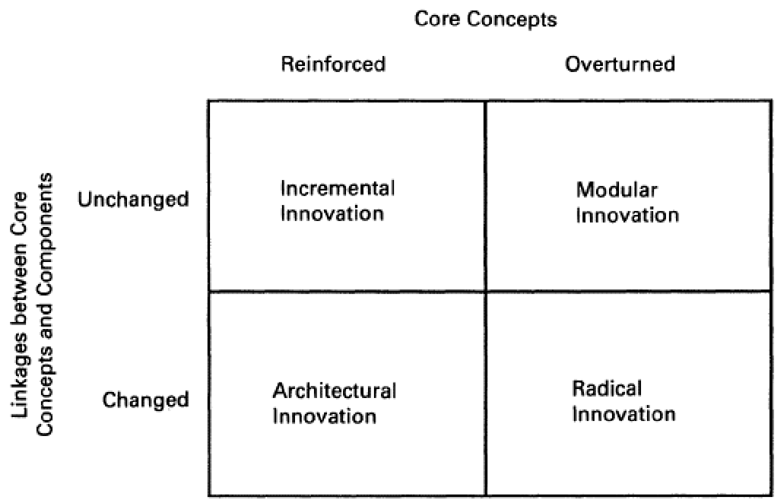

Figure 7: A categorization of 4 types of innovation based on linkage and core concept changes (M. Henderson and Clark, 1990).

When examining a product it can be viewed either as a system or as a set of components, and it requires knowledge in both areas: component knowledge and architectural knowledge. The knowledge of the component concerns the core design concepts, and how they are applied in a specific component. The architectural knowledge concerns how the different components are integrated and interrelated to the entire system.

Companies need to recognize if they are doing architectural innovation because it may exceed the knowledge of the established company. This can be difficult for the established company to recognize but also to redress since it tends to be embedded in the structure and procedures. A lot of the architectural knowledge can be useful knowledge in the innovative process, however, some of the knowledge is not useful and become an obstacle to the innovation. It can have severe consequences for the firm that architectural knowledge tends to be reused in the innovation project when it is not in the best interest of the innovation.

When a dominant design is chosen and established, the company often wants to obtain economies of scale and take advantage of externalities. When the dominant design is accepted, it is not reevaluated. The components are shaped to fit the chosen design.

The organization interacts with customers, suppliers, and other stakeholders through its communications channels. These can be formal or informal but they are critical to the design because they are a crucial source of knowledge. The way the channels are formed reflects the readiness of the organization to acquire knowledge. A huge information flow creates a need for the organization to develop filters to classify information. As time passes, there will be a change in what is important knowledge for the organization, and the channels and filters must be adjusted accordingly. This will help engineers in solving specific problems because they have achieved knowledge from their previous projects and thus developed problem-solving strategies. The channels, filters, and strategies reflect the architectural knowledge of the organization. When doing architectural innovation established organizations tend to use well-known channels, filters, and strategies, however, they are unaware that they have created path dependencies. New companies must create new channels, filters, and strategies, and they do not have embedded irrelevant architectural knowledge. Organizations that are fast-learning and effectively orchestrate new component technology may be ineffective when it comes to new architectural knowledge. Thus, an established organization needs to have the highest attention to its learning methods, and consider that architectural innovation may require an organization and employees with different capabilities and learning methods.

4.3.1 Part conclusion

Designing a hydrogen supply chain has several focus points. There must be a focus on technological efficiency, but also on how the focal firm can transform its resources and knowledge into a valuable product, that the possible adoption chain actors are willingly investing in. However, another important aspect for the focal firm to consider is whether itself stands in the way of creating a successful innovation product because it reuses existing resources and capabilities which are not applicable to the innovation project. M. Henderson and Clark (1990) emphasizes that this is often a forgotten point, and, thus, awareness of it is essential for the focal firm.

4.4 Collaborating in an innovation ecosystem

Previous sections showed that the road towards a hydrogen economy has many roadblocks. DNVGL (2021) has examined what the actors identify as the biggest challenges, and where the greatest risk lies. On top of their concern are the high cost of hydrogen, lack of predictable regulations, hydrogen infrastructure, lack of investment in hydrogen technology innovation, and a potential shift in governmental support. As described in the limitation section 2.4 the master thesis will address the barriers in the hydrogen supply chain from an innovation ecosystem perspective. The theory will be used to examine how it can assist in securing alignment between actors when barriers are many, and uncertainty is high.

This section will present four theories on the innovation ecosystem in combinations with frameworks that can be used to mitigate the co-innovation and adoption chain risks that are an important aspect in an innovation ecosystem. See figure 1 for the structure of the thesis.

- **Section 4.4.1** Match Your Innovation Strategy to Your Innovation Ecosystem by Adner (2006)
- **Section 4.4.2** The Wide Lens by Adner (2012)
- **Section 4.4.3** Co-Opetition by Nalebuff and Brandenburger (1997)
- **Section 4.4.4** MIT's Stakeholder Framework for Building Accelerating Innovation Ecosystems" by Budden and Murray (2019)
- **Section 4.4.5** Que Sera, sera? Conceptualizing business network foresighting by Andersen et al. (2018)

4.4.1 Match Your Innovation Strategy to Your Innovation Ecosystem by Adner (2006)

Adner (2006) defines an innovation ecosystem as:

> "An innovation ecosystem is the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors."

The essence of collaborating in an innovation ecosystem is, that when organizations and institutions join forces, they can present products and services that are more innovative than one actor could have presented alone. This is due to the complexity of society where few companies alone have the needed resources and capabilities to present fully integrated and innovative products (Adner, 2006).

Collaborating in an innovation ecosystem can lead to new opportunities, however, there are also challenges when innovating in an ecosystem. Adner (2006) emphasizes in the article "Match Your Innovation Strategy to Your Innovation Ecosystem" that it can lead to new dependencies, which can have big consequences for the corporation, and the corporations have to counterbalance if the risk is worth taking. Adner (2006) talks about three fundamental types of risk; Initiative risk, Interdependence risk, and Integration risk

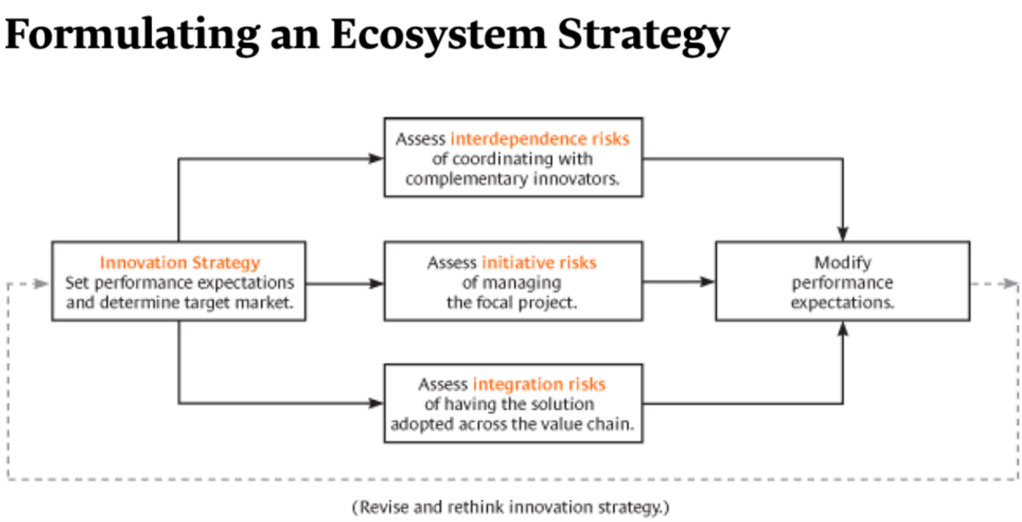

Figure 8: The three types of risk present in an innovation ecosystem (Adner, 2006)

The initiative risks treat the familiar uncertainties that are present when managing a project. The interdependence risk is the risk associated with the uncertainties of coordinating with other innovators. The integration risk presents uncertainties when adopting processes across the supply chain. When companies adopt processes or products, it will lead to a greater or lesser degree of dependency on the technology. The corporation will strive to mitigate these risks as it best can.

To raise the probability of creating project success in the innovation ecosystem the risks must be properly managed. The execution of the project has to be properly planned, but an alignment of the expectations of the project is also crucial. Assessing the risks is important for creating the best basis for the right expectation. A poorly assessed risk profile can result in raising expectations on insufficient grounds and make actors unaware of what they can expect in the future. If some of the risks are very high, it does not necessarily mean that actors should not invest in the project, it just means that the strategy shall be planned accordingly. Understanding the overall picture from the co-innovators perspective is important, and as Adner (2006) described: "a complete view of the different ecosystems is the key to effectively assessing options and prioritizing opportunities"

Where to compete, when to compete, and how to compete
The challenges that occur outside the corporation's usual boundaries shall be recognized, and Adner (2006) does this by considering the questions "where to compete, when to compete, and how to compete" in a nontraditional way. When making a strategy in an innovation ecosystem it must be realized that mistakes during the process, failure, delays, miscommunication, and technical challenges are unavoidable. These risks have to be taken into account when asking and answering questions, and in this way, the corporation gains knowledge about the industry, capabilities, challenges, and the other actors in the ecosystem. When a strategy has been settled describing where, when, and how to compete, the company has gained an overview of the ecosystem, and when actors shall carry out specific actions. This is a very important step in collaborating in an innovation ecosystem because being late is not desirable and nor is being early if the innovation project depends on co-actors that are not ready Adner (2006). Adner (2006) emphasizes that it is important for the actors to build a strategy upon these questions, but he does not comment on how to approach them. However, this is the intention and focus of the book "The wide lens" by Adner (2012), which is treated in the next section.

4.4.2 The Wide Lens by Adner (2012)

In the book "The wide lens by" by Adner (2012), Adner gives his view on how to manage an innovation ecosystem. He describes how the actors should use a wide lens when collaborating on innovation projects. As Adner (2006) shows it is not sufficient to only focus on the execution of the innovation but also on the expectations. Adner (2012), thus, presents 8 frameworks that can be used to understand the ecosystem in depth. The frameworks can raise the odds of success with the co-innovating project, and supply knowledge when building the strategies. The title of the book "The wide lens" refers to the way corporations shall think when co-innovating. They shall not only focus on their expectations, their issues, what they think is the optimal solution, and how they think the strategy shall be executed. To succeed they need to use a wide lens and take their co-innovators point of view. What are the co-innovators expectations, their issues, what do they think are the optimal solutions, and how do they think the strategy shall be executed? To raise the odds for project success, the co-innovators, and the focal firm shall be aligned on those parameters.

In The wide lens, Adner also reconsiders the innovation ecosystem risk that he presented in Adner (2006). The three types of risk are execution risk, co-innovation risk, and adoption chain risk. The risks are displayed in figure 9. The execution risk covers the challenges that are present for the innovation project to meet certain specifications within the given time. The co-innovation risk covers the extent to which the success of the focal firm's innovation project relies on the success of other innovation projects. The adaption chain risk is about challenges that occur when other actors need to adapt the innovation by the focal firm before the innovation is deemed successful Adner (2012, p. 34). These risks have to be confronted from the beginning of the project as Adner (2012, p. 64) states: "Risk can be managed proactively, but only if it is recognized in advance".

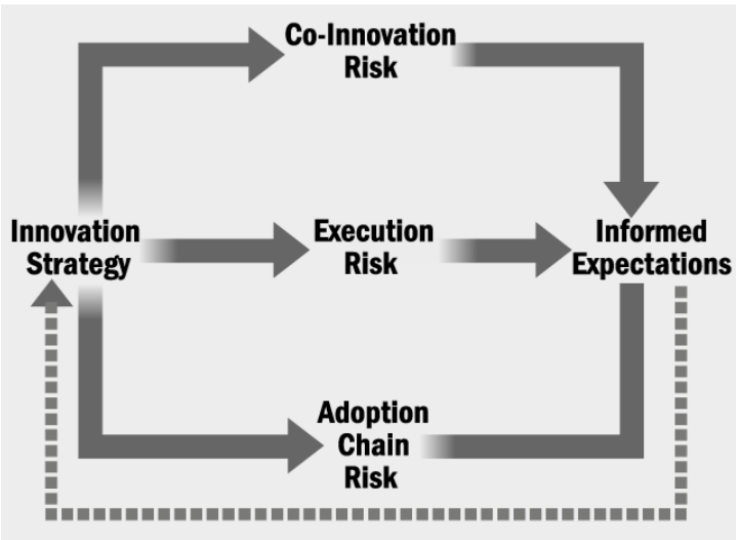

Figure 9: The three risks that shall be considered in a innovation ecosystem (Adner, 2012).

First-mover advantage
When evaluating whether there is a risk of co-innovation dis-alignment, the aspect of whether or not there is a first-mover advantage. Adner (2012, p. 140) highlights this as an important field to assess when innovating. Will it be an advantage for the focal firm to get early on the market,

or will it be smart to wait until the market is ready? When the focal firm is innovating in an environment where they are depending on co-innovators to launch their innovation, the focal firm can end up in quadrant 3; the hurry up and wait. Their product is not fully functional because they have to wait for other innovations to complete. This will endanger the success of the focal firm's innovation. In The wide lens, Adner claims that this is often the case. Instead of thinking about being a first-mover, there should be more focus on being a smart mover.

		COMPLEMENTOR CO-INNOVATION CHALLENGE	
		LOWER	HIGHER
INNOVATOR EXECUTION CHALLENGE	LOWER	*Quadrant 1: First in Gets the Win* - Baseline level of early-mover advantage	*Quadrant 3: Hurry Up and Wait* - Reduced level of early-mover advantage
	HIGHER	*Quadrant 2: Winner Takes More* - Increased level of early-mover advantage	*Quadrant 4: It Depends* - Level of early-mover advantage depends on which challenge is resolved first

Figure 10: The first-mover matrix by Adner (2012).

The Value Blueprint

The central framework in the book by Adner (2012) is the value blueprint. It can be used to structure and map the innovation ecosystem and thereby give an overview of actions required at a given time together with a notice of its status. The knowledge gained from using for example the first-mover matrix and mapping the ecosystem risk can be used in the value blueprint to display the landscape of the innovation project. The following steps shall be performed to construct the value blueprint (Adner, 2012)

- (1) Identify your end customer
- (2) Identify your own project
- (3) Identify your suppliers
- (4) Identify your intermediaries
- (5) Identify your complementors
- (6) Identify the risks in the ecosystem
- (7) For every partner whose status is not green, work to understand the cause of the problem and identify a viable solution
- (8) Update the blueprint on a regular basis.

When the value blueprint is developed each action will be provided with a green, yellow or red traffic light symbolizing any obstacles needed to be considered before going to the next step. Green represents that the action will take place smoothly. Yellow light represents a minor obstacle that is expected to be remedied, but an eye shall be kept on it. Red light represents a serious obstacle that needs immediate attention. The value blueprint displays in a simple way the central elements of the projects, its co-actors, and the concerning risk.

4.4.3 Co-Opetition: Competitive and Cooperative Business Strategies for the Digital Economy by Nalebuff and Brandenburger (1997)

The article by Nalebuff and Brandenburger (1997) discusses the game theory in business and the opportunities it opens. "Game theory is a systematic approach to discovering new strategies and changing the game. It helps you to keep your eye where the real action is and to find a different and better game to play"(Nalebuff and Brandenburger, 1997). The actors need an eye on the fact that one actor does not lose when the focal company wins; they also win. Such actors are called complementors. An actor is a complementor if "customers value your product more when they have that player's product than when they have your product alone"(Nalebuff and Brandenburger, 1997). Contrary to this, that the customers value your product less, the player would be a competitor. The definition is essential. The focal firm needs to be aware of this distinction because they must manage differently. If the focal firm works together with complementors it creates new market opportunities for every participating actor.

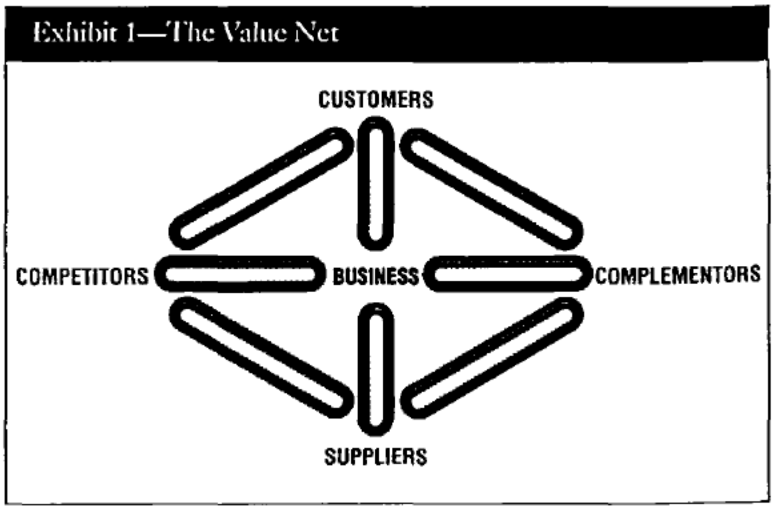

Figure 11: The value net (Nalebuff and Brandenburger, 1997)

Nalebuff and Brandenburger (1997) uses the framework Value Net in figure 11 to assess which suppliers and customers are competitors and complementors. The focal firm must assess which aspects that make the innovation more valuable, and what can be done to create a need for the innovation? Taking an outside-in perspective can help the focal firm to understand how the other players relate to you, and whether you are competing or cooperating for market shares. What will other players lose if the focal firm is not in the game? Are you replaceable? Furthermore, what will the focal firm lose if other actors are not in? If other players are depending on the focal firm's product and the firm adds value throughout the game, it can gain more market share in the end.

At the end of the article by Nalebuff and Brandenburger (1997) is a checklist for change management. The purpose of the list is to force the company to consider aspects that identify how they can capture or create more market share by taking an outside-in perspective. A checklist for change (Nalebuff and Brandenburger, 1997):

- Use the co-opetition mindset. Think about creating and capturing pie - competing and cooperating.

- Write out the Value Net for your organization. Describe the whole game. Identify all the players and their relationships. Think about complements. List the players you would like to bring into the game.
- Calculate your added value. Think about how you can increase your added value. Use the concept of added value to understand who has the power in your game.

4.4.4 MIT Stakeholder Framework for Building Accelerating Innovation Ecosystems" by Budden and Murray (2019)

Adner (2006) described the ecosystem actors as the involving actors, institutions, and complementary relations that are important to the focal firm's innovative performance. This definition lists a large number of actors, and the article by Budden and Murray (2019) is used to get a picture of these actors. Budden and Murray (2019) addresses which actors should be present in an innovation ecosystem to secure a foundation for the optimal innovation-driven environment in the local region. The data by Budden and Murray (2019) is based on a worldwide innovation ecosystem as well as MIT classes and their global program MIT REAP, which engages communities to develop and strengthen innovation-driven entrepreneurial ecosystems. MIT is part of the Greater Boston ecosystem. The article seeks to support and provide advice for the actors who are interested in optimizing the innovation-driven entrepreneurship within a specific region (Budden and Murray, 2019). The framework maps out the needed stakeholders that must be present to drive the innovation. The five stakeholders in an innovation ecosystem are defined by MIT to be entrepreneur, risk capital, corporate, government, and university. They are shown in figure 12 and explained in the following.

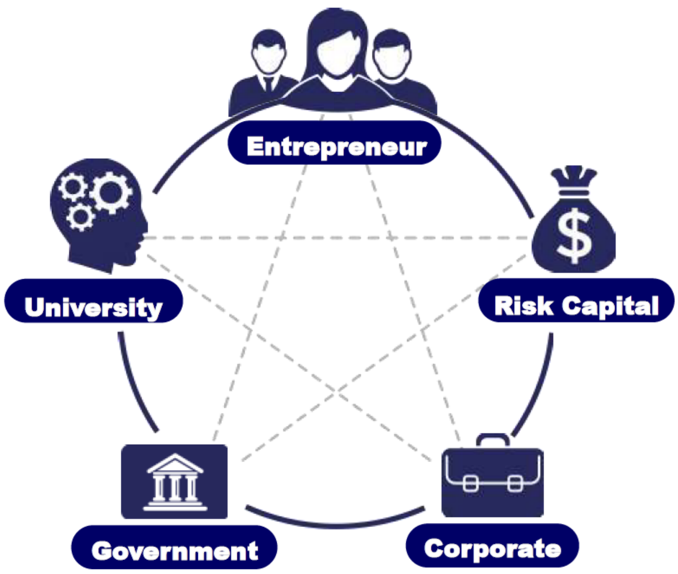

Figure 12: The stakeholder framework for innovation ecosystems by Budden and Murray (2019)

Entrepreneurs are the first stakeholders, and they are characterized by having a focus on hard core innovation, fast-growing, and scale beyond local markets. In innovation ecosystems, these entrepreneurs are called innovation-driven enterprises (IDE). IDEs distinguish themselves from small and medium-sized enterprises (SMEs) in the way they IDE aim to build their business model on innovation and thereby gain a competitive advantage. Further, they aim to grow and scale quickly beyond the local market. The intention of SMEs can be the same, however, they do not have the same network and resources as IDEs benefit from, which are essential to driving the start-up successfully. The IDEs are at the frontline of innovation, and they are essential for the innovation ecosystem because they devise new areas for innovation.

Risk Capital are providers of risk capital, and they are joining in the innovation ecosystem building activities. They are engaged in the ecosystem beyond by being funders. They also provide access to where risk capital resources are limited. This could be the social network for identifying new ideas and new IDEs in the region.

Universities are the third stakeholders that play an essential role in an innovation ecosystem. MIT and Harvard are universities present in the Greater Boston ecosystem, Stanford in Silicon Valley, and other universities play significant roles in other innovation ecosystems for example in Israel, London, New York, and Singapore. The role of the universities is to provide education, facilities, technical and scientific training, and fundamental research.

Large corporations often describe themselves as global and multi-national corporations that are not that dependent on a specific region and therefore not depending on any ecosystem. However, there is an increasing tendency for large corporations to recognize the capabilities of innovation ecosystems. They play an essential role in building ecosystems, contribute to talent development through regular jobs, contribute with corporate venture capital (CVC), and can lend their technical facilities, hereby supporting innovation in the ecosystem.

The government is the fifth key stakeholder. If the government is actively engaged and secures good conditions for the ecosystem it can make a world of difference to the development of the innovation ecosystem. The government representatives can come from the national, regional, or city levels of public administration. However, it can also be from departments or agencies at different levels, such as business, education, innovation, or trade.

Other key players are also present in the innovation ecosystem, however, they vary from region to region. These players could be specialized services providers, NGOs, financial institutions, etc.

Identification of the actors is beneficial to a focal firm because they are the building blocks of the ecosystem. This can be used to contribute to the community as well as gain insights into how to capture and create value in the innovation ecosystem

4.4.5 Que Sera, sera? Conceptualizing business network foresighting by Andersen et al. (2018)

The last article discussed in this section is by Andersen et al. (2018). It gives another perspective on how a business network can achieve alignment among actors throughout the project. Andersen et al. (2018) emphasize that a business network and its relationships are dynamic, and the purpose and participating actors transform with time. Issues, solutions, and perceived actions from the business partners differ from the perspective taken. This is an unavoidable situation in a business network and can be compared to aligning of actors in an innovation ecosystem. Andersen et al. (2018) develops a framework for picturing the issues, solutions, actors, and actions that exist in the business network. By picturing it, it is possible to get an indication of when issues, solutions, and activities overlap with other actors. This creates an opportunity to allocate resources and activities optimally. It can furthermore be used to unveil where actors, solutions, and actions are not streamlined.

The framework displayed in figure 13 will expose what solutions solve which issues and whether some actors have an issue, that has been resolved by other actors.

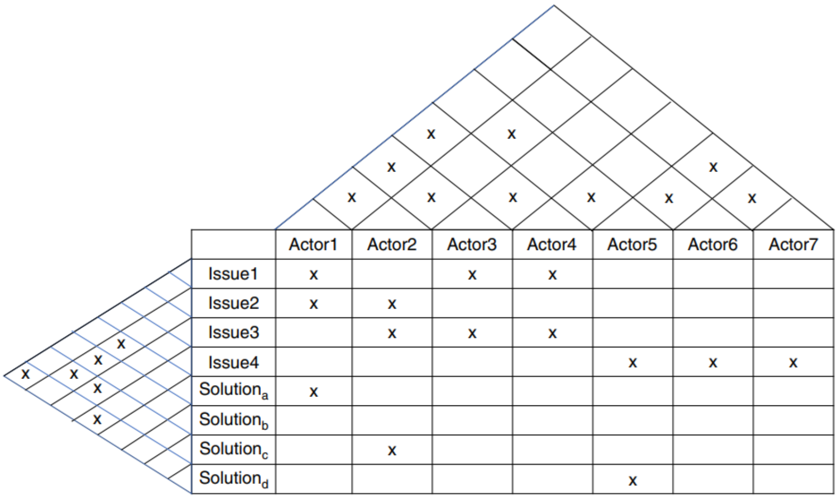

Figure 13: The issue/solution matrix by Andersen et al. (2018)

4.5 Part conclusion

Innovating in an ecosystem creates a possibility for companies to join forces and create a product that no actor could have done on its own. However, with an increased number of opportunities comes to an increased amount of adoption chain and co-innovation risk. Awareness of them is essential for raising the odds of innovative success. The chosen theories can bring valuable knowledge into different areas of the innovation ecosystem. A central framework to describe the innovation projects, their co-actors, and the concerning risk is The value blueprint by Adner (2012). Assisted by other frameworks from The wide lens by Adner (2012) it can be used to understand and display the associated risk that is present. The framework by Budden and Murray (2019) gave an insight into the different roles of the specific actor in the ecosystem and why they are important. Finally, Andersen et al. (2018) gave another view on how the alignment of co-actors can be obtained by focusing on the many issues and solutions that the different actors have.

5 Conceptual framework

In chapter 4 knowledge in four areas was obtained to get an understanding of how supply chain actors can be aligned when collaborating in an innovation ecosystem. The theories on innovation ecosystems emphasize the importance for the focal firm to take the perspective of the other co-actors to increase the odds of success. This chapter will focus on how the different frameworks can be integrated to support each other and, thus, give the focal firm a deep understanding of how the innovation depends on co-innovators and adoption chain actors, and how these can be aligned. The conceptual framework will be used to answer RQ2: *Examine how one specific barrier is understood and managed by three actors within the supply chain of the maritime sector with the use of the developed conceptual framework.*

The first section 5.1 introduces the initial conceptual framework which was developed in the specialization project by the undersigned (Nissen, 2021). This framework was developed based on the knowledge from the Nissen (2021). However, with the knowledge foundation from chapter 4 in this master thesis, the initial conceptual framework was further developed and the revised conceptual framework will be presented at the end of this chapter in section 5.2. See 1 for the structure of the thesis.

5.1 Initial conceptual framework

In the specialization project by the undersigned (Nissen, 2021), a conceptual framework was developed on how to perform a stakeholder mapping analysis from an innovation ecosystem perspective. The initial conceptual framework is developed by integrating relevant theories and frameworks, and its purpose is to align the relevant stakeholders and secure this alignment throughout the development process. The steps to perform are listed below and also displayed in figure 14. The framework will briefly be described in this section. For a deeper explanation refers to Nissen (2021).

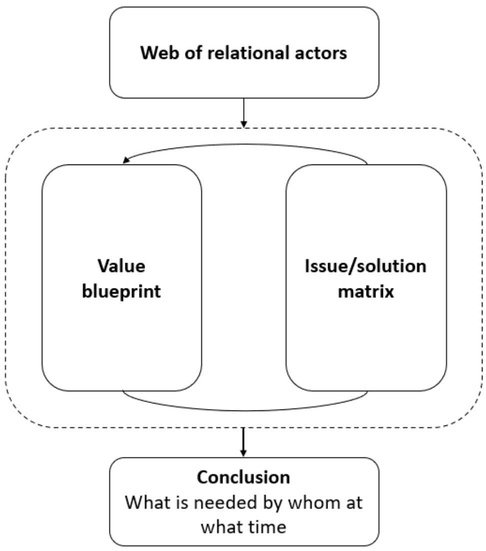

Figure 14: The initial conceptual framework for performing a stakeholder mapping from an innovation ecosystem analysis perspective (Nissen, 2021)

Steps to follow in the conceptual framework:

1. Develop a web of relational actors
2. Develop a issue/solution matrix
3. Develop a value blueprint
    (a) Identify your end customer
    (b) Identify your own project
    (c) Identify your suppliers
    (d) Identify your intermediaries
    (e) Identify your complementors
    (f) Identify the risks in the ecosystem
    (g) For every partner whose status is not green, work to understand the cause of the problem and identify a viable solution
    (h) Update the blueprint regularly

The first step is to gain an overview of the actors by developing The web of relational actors by Wit and Meyer (2010). This sets the landscape and gives an overview of how the actors are related. It indicates the most important actors, and how they can influence the development of the process and the final product. To support The web of relational actors the framework Issue/solution matrix Andersen et al. (2018) is used to gain a full overview of the issues and solutions that are present in the project. In co-developing a product it is often taken for granted that all actors are sharing the same issue and solution. This is, however, not always the case it can lead to product failure or delay in the development process. The issue/solution matrix is used to verify that the developed solution does indeed solve all the issues. The knowledge from the web of relational actors and the issue/solution matrix is used to develop the final value blueprint. The value blueprint illustrates the relevant stakeholders and the actions that need to take place for the development process to succeed and to secure alignment throughout the process.

5.2 Revised conceptual framework

In this section, the conceptual framework presented in the specialization project (Nissen, 2021) will be updated in light of the knowledge obtained in chapter 4. The initial conceptual framework focuses on building a solid knowledge foundation for the value blueprint, however, it is missing the extra awareness of the ecosystem risk, especially in regards to the co-innovation risk, adoption chain risk, and the hidden dis-alignment of actors. The revised framework will have an extra focus on the knowledge used to develop the value blueprint. Instead of concluding by applying the value blueprint, the revised conceptual framework will use it as the central framework that will display the information gained on innovation ecosystem actors, barriers, co-innovation risk, and adoption chain risk.

The specific purpose of the revised conceptual framework is for the focal firm to get a comprehensive understanding of the innovation in relation to co-innovation and adoption chain risk, and how these can be managed to secure alignment. The new structure intends to obtain knowledge on relevant aspects but continuously discuss its relevance to the innovation project. The revised conceptual framework consists of 8 parts. They are further explained in the following section and illustration in figure 5.2.

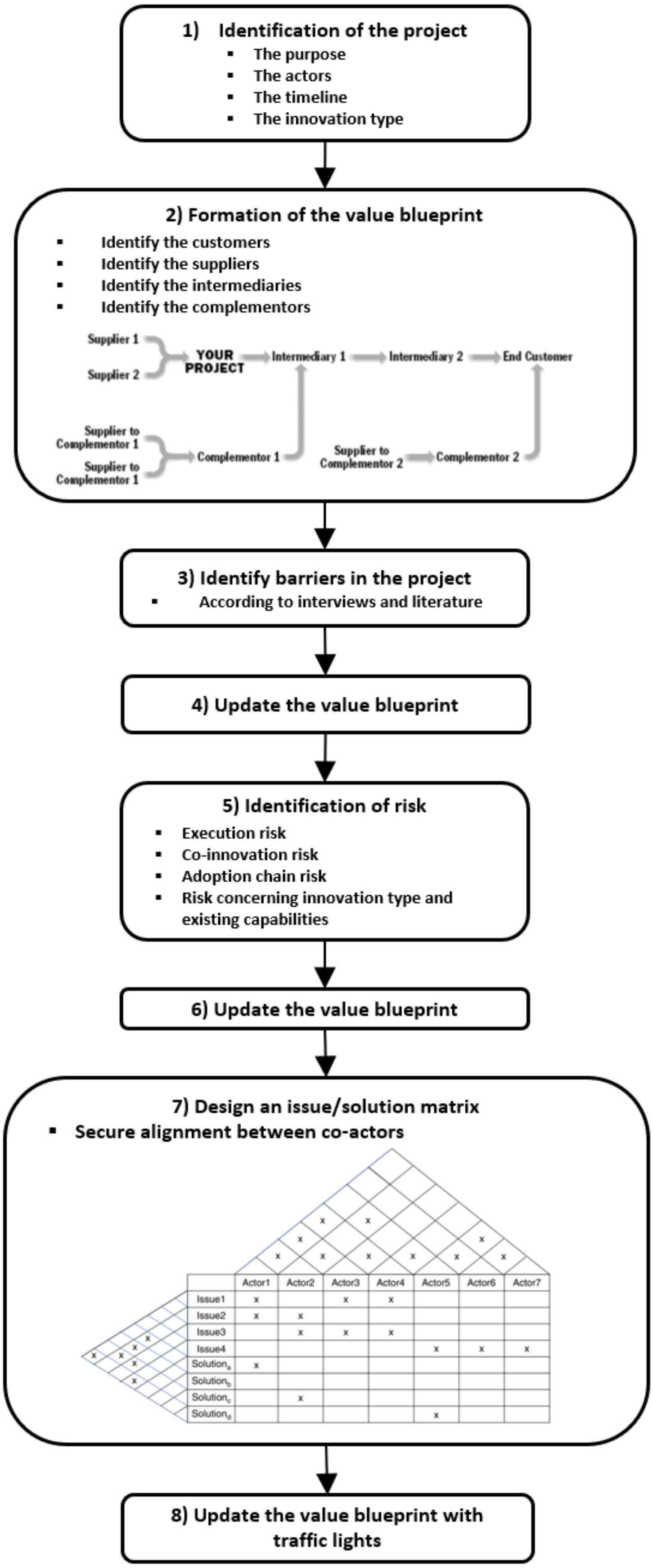

Figure 15: The revised conceptual framework with the use of the value blueprint by Adner (2012) and the issue/solution matrix by Andersen et al. (2018).

1) Identify your own project

- The scope of the project

    The purpose

    The actors

    The timeline

- The type of innovation

The first step focuses on understanding the scope of the project from the perspective of a focal firm. This implies describing the purpose of the project, the actors, and the timeline of the project, and answering the questions about where, when, and how to compete. When the scope is set, it defines the kind type of the innovation project. This step is developed based on Adner (2006) and Adner (2012) and their thoughts on defining the scope of a project.

2) The formation of the value blueprint

- Identify the customers
- Identify the suppliers
- Identify the intermediaries
- Identify the complementors

In this step, the first draft of the value blueprint will be created (Adner, 2012). It uses the knowledge from step 1), and displays who the customers, suppliers, intermediaries, and complementors are. It will advantageous to map out the entire landscape of the relevant stakeholders since it will reveal if actors are forgotten. This can contribute to the success of the project.

3) Identify barriers in the project
The value blueprint from step 2) is now augmented with actions and actors that will take part in the execution of the project. In step 3) barriers relevant to the project are identified in the literature and from the conducted interviews. This step is important to secure a realistic view of the environment of the project participants.

4) Update the value blueprint
The value blueprint is once again updated with new information from step 3). If some of the barriers are critical to the execution of the project, they shall be considered and defined, and managed.

5) Identification of risks
The next step is to identify the risks that exist when innovating with other actors. The execution risk, the co-innovation risk, and the adoption chain risk will be considered(Adner, 2012). Furthermore, based on the theory by M. Henderson and Clark (1990) it shall be considered if there is a risk related to the innovation type, and how the focal firm will drive the innovation.

6) Update the value blueprint
The value blueprint is once again updated with the results from step 5).

7) Develop the issue/solution matrix

The issue/solution matrix is created to secure alignment between the co-actors and to display hidden red lights that have not been managed so far.

8) Update traffic lights regularly

The environment and the circumstances change during the lifetime of a project. The actions that must take place shall be evaluated to handle any barriers or road bumps in the execution of the action. If there is no hindrance for the action to happen it is marked with a green light. If some hindrances will be solved in a near future, they will be marked with a yellow light. Finally, if there are actions that can not take place unless some challenges are solved, then they are marked with a red light. Some actions have green flags in the beginning but circumstances or new information turn them red later on. The conceptual framework requires an iterative process and must be updated regularly.

5.3 Part conclusion

The revised conceptual framework will be applied to the case presented in chapter 6 to better understand how actors in a supply chain act upon perceived barriers in relation to co-actors. When the conceptual framework is applied by a focal firm, they shall gain a better overview of the innovation project, its risk in relation to co-innovation and adoption chain actors, and how alignment between the actors can be managed. The conceptual framework will be applied in chapter 7 with the knowledge from the three conducted interviews to answer RQ2: *Examine how one specific barrier is understood and managed by three actors within the supply chain of the maritime industry with the use of the developed conceptual framework.* In the discussion section 8 the applied framework will be evaluated by using the Gioia methodology. The revised conceptual framework will be named "conceptual framework" in the rest of the thesis for the sake of ease.

6 The case

TrønderEnergi is a part of an Enova application process to become a maritime center of hydrogen fuel. Enova is a state-owned enterprise that is owned by the Norwegian ministry of climate and environment and is financed by the Energifondet. The objective of Enova is to play a role in increasing innovation within energy- and climate technology that will lead to zero-emission. Furthermore, Enova shall increase the security of supply and reduce greenhouse gas emissions in accordance with the Norwegian climate commitment (Enova, 2022). 15 companies in the application process are spread out along the coast of Norway, from south to the north. 3 to 5 companies will receive up to 150 a million NOK grant to advance the development of hydrogen production (Enova, 2021). TrønderEnergi is collaborating with co-innovators in the application process. In this process, they have to examine everything needed for establishing hydrogen production. One of the main aspects they have to consider is the market. TrønderEnergi will supply a market in Trøndelag, and therefore they are in contact with local actors to examine the projected demand in the future. In section 6.2 the elements of the hydrogen supply chain are described. But first an introduction to fundamental knowledge on hydrogen and hydrogen technology in section 6.1.

6.1 Hydrogen technology

Hydrogen fuels are expected to become one of the dominant energy carriers of the future because they can be produced without any greenhouse gas emissions. However, 95% of the hydrogen produced today is made from natural gas with steam reforming, a process that produces lots of CO_2 (Hub, 2020). Hydrogen comes in three categories as shown in figure 16. Hydrogen from natural gas with steam reforming is referred to as grey hydrogen due to its emission of CO_2. If the CO_2 is stored or re-used it is referred to as blue hydrogen. Blue hydrogen is CO_2 neutral but it is still produced from fossil fuels. The type of hydrogen this master thesis will focus on is green hydrogen, which is produced by splitting water into hydrogen and oxygen by electrolysis powered by renewable energy. In the production of green hydrogen, there is no CO_2 or GHG emission.

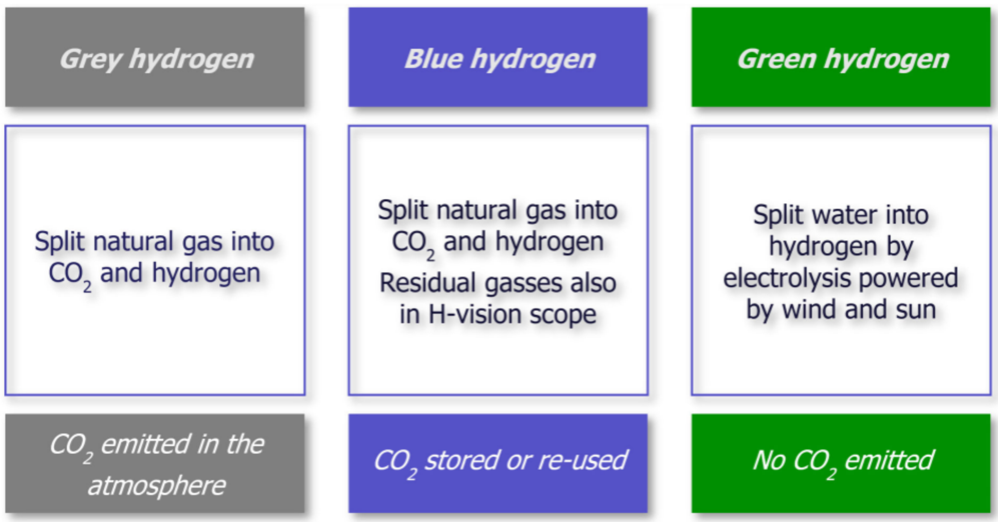

Figure 16: Hydrogen is categorized as grey, blue or green depending on the extracted and production method (Partenie et al., 2019).

The establishment of a hydrogen supply chain consists of six steps and they are described in the following:

1. Access til renewable power
2. Production of hydrogen using electrolysis
3. Compression of hydrogen for storage
4. Bunkering of vessels
5. Hydrogen used as fuel onboard ships
6. Customers acceptance

Step 1) Access to renewable power

To produce green hydrogen the electricity utilized must come from a renewable source. In 2020 the power production in Norway consisted of 88% water power, 9% wind power, 1% from other renewable sources, and the last consist of gas, coal, and nuclear power which is mainly bought from the common European power market (NVE, 2020). Due to the high amount of renewable energy in the Norwegian grid, it is easy to get renewable power for hydrogen production. However, whether this will be the case in the future is unsure. The system operator of the Norwegian power system, Statnett, says that the southern part of Norway can be in shortage of power next year and, thus, need to import power (Statnett, 2022). The imported power will not necessarily be from renewable sources. Trøndelag, where TE examines to place the production, in the middle part of Norway will not be affected in the same way, but this can change in the future.

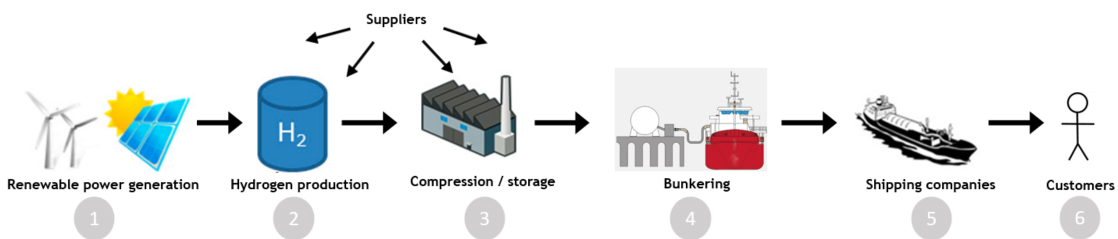

Figure 17: A simple figure of the main parts of the supply chain of compressed green hydrogen. Pictures from Trelleborg (2022) and Ozawa et al. (2017).

Step 2) Production of green hydrogen using electrolysis technology

Green hydrogen is produced by the electrolysis of water. Figure 18 displays how water is split into hydrogen and oxygen with the use of an electrolyzer(Partenie et al., 2019). When converting electrical power into fuels, the efficiency of the electrolysis process is crucial. According to Stattnet (2018), the efficiency is approximately 60% for. The more efficient the conversion, the more attractive to convert energy to hydrogen instead of using it in other ways. 60% is not an excellent efficiency, however, if the produced heat is utilized it raises the efficiency considerably.

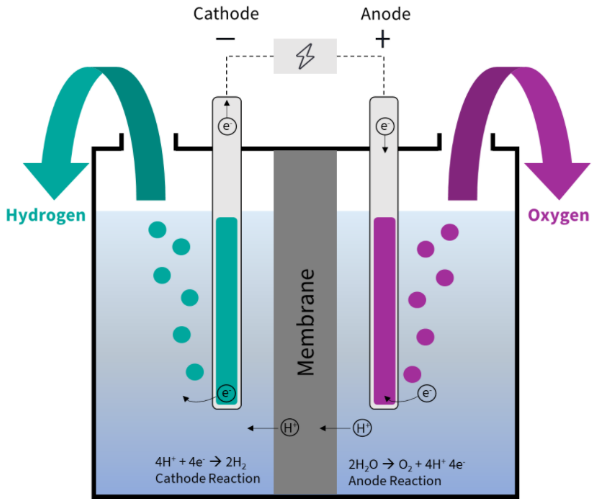

Figure 18: Green hydrogen is produced by electrolysis of water powered by renewable energy. The figure shows how H2O is split into hydrogen and oxygen (DiChristopher, 2021).

Step 3) Compression and storage
For storage and distribution compression of the hydrogen takes place. Hydrogen is the lightest element and has the lowest density of all gasses. Therefore it must be compressed to between 350-700 bar.

Step 4) Bunkering of the vessel
The next step is bunkering of the vessel. Currently, the bunkering technology is not commercialized. With current technology, it takes too long to bunker the vessel. The long bunkering time is not acceptable for the shipping companies, and other solutions are examined. One option could be a container swapping solution, where the hydrogen is compressed directly into the tanks. The tanks will be craned on the vessel. When the vessel comes back to the port weeks later, the empty tanks are then swapped with full ones. This technology is not commercialized yet but is expected to be ready by 2024 (Statkraft, 2022).

Step 5) Hydrogen used as fuel onboard ships The hydrogen is now loaded on the vessel and ready for use. The next step is to convert the hydrogen into propulsion power. One option is to burn it in an internal combustion engine (ICE). This is by far the most common choice for maritime vessels. The ICE was designed for fossil fuels, but soon hydrogen can be used as fuel in a solution dual-fuel internal combustion engine (DF-ICE) (Solutions, 2022b). The DF-ICE can alter between two fuel types, hydrogen and diesel, depending on accessibility and price, and, thus, not become path dependent on hydrogen.

Another option is to convert hydrogen directly into electrical power with the use of a fuel cell. Dual-fuel ICE and fuel cells have their advantages and disadvantages. One important aspect is efficiency. The combustion engine has an efficiency between 40% and 50% at its best(Wärtsilä, 2022), while the fuel cell has an efficiency of about 60% (Efficiency and Energy, 2022). If losses in transmission, fuel cell, etc. are taken into account, the round trip efficiency is as low as 18-42% for the hydrogen supply chain (DiChristopher, 2021). The round trip efficiency is from the production of hydrogen by electrolysis to hydrogen consumed with the fuel cell. The low round trip efficiency is a major problem. There is thus a big focus on choosing and developing technologies to increase efficiency.

Step 6) Customers of the shipping companies The last link in the supply chain is the customer. The willingness to pay to get a product that has used CO2-neutral shipping is necessary to create the demand.

6.2 The supply chain actors

Currently, there is little demand for hydrogen, but lately, there has been an increasing interest in it. However, the interest has to be converted into an actual need and a demand. This master thesis will examine the actors in the hydrogen on both supply and demand side, a examine what is needed for them to change their interest into action. This is not an easy task. To transform hydrogen into an interesting topic and create an actual demand, many barriers must be managed. As described in section 4.2 it is not one single barrier but a whole chain of barriers within almost every element of the supply chain that needs to be managed. It calls for collaboration between the actors to work on the issues parallel. According to the theory of innovation ecosystems -see section 4.4- actors who collaborate and participate in an innovative environment can jointly work together and share knowledge and capabilities to develop the needed technology and overcome the barriers. This case will focus on 3 actors in an actual innovation ecosystem. TrønderEnergi, The Ocean Hyway Cluster, and the shipping company AQS.

They have been chosen to get a broad understanding of the supply chain from both a supply and demand perspective. They give insight into how they perceive barriers, criteria for investing, and how certain issues in the supply chain can be solved. In figure 19 the supply chain for compressed hydrogen for the maritime sector is visualized. The supply chain consists of the main areas of renewable power generation for hydrogen production with compression, storage, and bunkering facilities for maritime use. In the case study, the first three steps are represented by TrønderEnergi. The compressed hydrogen is then sold and utilized by customers within the maritime sector. The customers are represented by AQS. Ocean Hyway Cluster has members in all the different segments within the supply chain, and they represent the voice of the entire supply chain, including suppliers that are not interviewed in the case study.

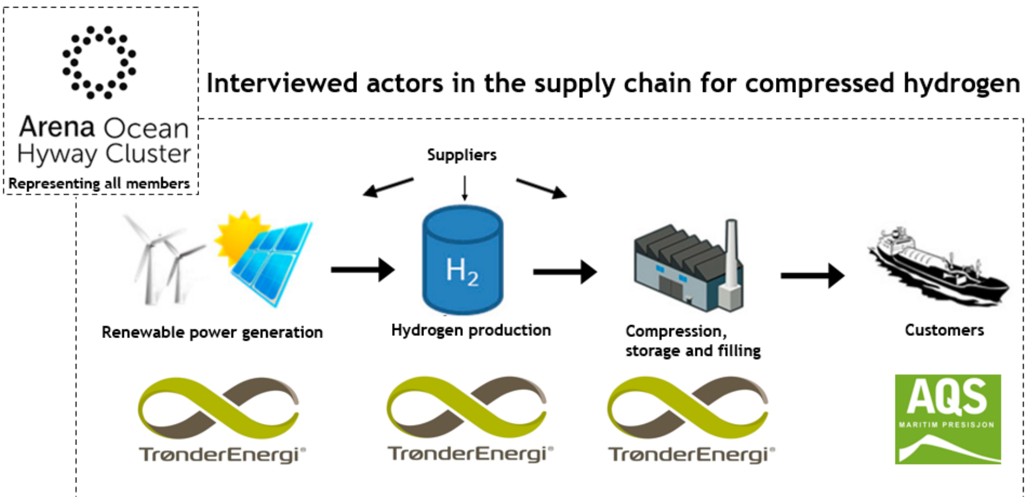

Figure 19: Interviewed actors in the supply chain. Pictures from Ozawa et al. (2017), TrønderEnergi (2022), AS (2022), and Cluster (2022).

Ocean Hyway Cluster

Ocean Hyway Cluster is a network focusing on hydrogen-based fuels for the maritime sector (Cluster, 2022). The network wants to promote the development of hydrogen-based solutions through knowledge sharing in an effort to make Norway a global leading actor within maritime hydrogen. Their focus is on gaining knowledge about the maritime sector and the current situation of hydrogen, promoting their cluster members, assisting them, as well as influencing government policy and regulations. With their 70+ members, they have great insight into barriers and drivers in the hydrogen busyness. Their members represent the following industries:

- Energy and hydrogen production
- Equipment suppliers
- Service suppliers
- Finance, public sector and regulation
- Ports and supply bases
- Research and education
- Design and yards
- Ship owners
- Clusters

TrønderEnergi AS

TrønderEnergi is a company focusing on energy-related services. The company operates in 3 main areas: production of water- and wind energy, and development of future energy-related services (TrønderEnergi, 2022). TrønderEnergi is owned by 19 municipalities in Trøndelag and KLP Pension. The subsidiary company TrønderEnergi Kraft AS owns and operates 23 hydro turbines and 9 wind farms, with an annual production of around 6.1 TWh of renewable energy. Technology and development form a unit with TrønderEnergi Kraft, and within this unit is the Hydrogen subunit. The unit of Hydrogen is established to examine how hydrogen can become a part of the future of TrønderEnergi. Currently, it is participating in the Enova application process which will support 3 to 5 selected companies that have developed a business case for producing hydrogen-based fuels for the maritime sector. There is tough competition between the 15 companies who are competing to receive the support. The selected companies must possess deep insights into the future hydrogen market in Trøndelag and Norway and a thorough knowledge of barriers and drivers(TrønderEnergi, 2022). TrønderEnergi is also a member of Ocean Hyway Cluster as an actor in energy and hydrogen production.

AQS AS

AQS is one of Norway's biggest shipping companies and maritime contractors(AS, 2022). It has specialized in aquaculture but also performs other activities such as service- and diving tasks. It has 19 service vessels and 160 employees and is currently the largest diving company in Norway with 65 divers. AQS has shown interest in hydrogen, and its view on the future of hydrogen-based fuels is important in realizing hydrogen as a future fuel. AQS is not a part of Ocean Hyway Cluster.

6.3 Part conclusion

The three actors; TrønderEnergi, AQS AS, and Ocean Hyway Cluster are investigating how hydrogen can become a part of their business. TE is a manufacturer of hydrogen, AQS AS as a maritime fuels consumer and OHC represents all its members from the entire supply chain. TE is seeking to get funding from the Enova fund, and they are, thus, investigating the market for opportunities and possible customers. AQS is a potential customer of TE. TE and AQS are positioned both upstream and downstream in the supply chain, and each has a different perspective on how hydrogen fuels can solve their issues and what the challenges and solutions are. Alignment between TE and AQS will be essential to raise the odds of creating a successful project with TE supplying the hydrogen demand of AQS.

7 Analysis

This chapter presents the analysis of the conducted interviews using the Gioia et al. (2013) methodology described in section 7.1. An example of how the analysis is conducted will be given. The complete analysis with the use of the Gioia methodology will be listed in tables from section 7.1.1 to section 7.1.8. In the conducted interviews TE, AQS, and OHC identify the barriers they see within the hydrogen industry. Their perception together with the identified barriers from the researched literature in section 4.2 forms the foundation for answering RQ1: "Identify general barriers in the supply chain for compressed hydrogen in the maritime industry" in section 7.2. One of the identified barriers is the maturity of hydrogen technology. This barrier will be studied in combination with the actors' answers from the interviews to verify the developed conceptual framework from section 5.2 and answer RQ2: "Examine how one specific barrier is understood and managed by three actors within the supply chain of the maritime industry with the use of the developed conceptual framework" in section 7.3.

7.1 Analysis with the use of the Gioia methodology

The analysis is performed with the methodology by Gioia et al., 2013 described in section 3. The analysis consists of three steps; 1st Order concepts, 2nd Order Themes, and Aggregated Dimension shown in figure 20. The first step is to list every concept TE, AQS, and OHC mentioned in the interviews. The concepts are categorized as the 1st Order Concepts. The second step is to give all 1st Order Concepts a 2n Order Theme. The 2nd Order Theme describes what the actor is trying to say in the 1st Order Concept. A pattern should emerge because several of the different concepts stated by the actors share the same 2nd Order Theme. If the 1st Order Concept is blank for some of the actors, it is because the respective actor did not comment on that specific topic in the conducted interview.

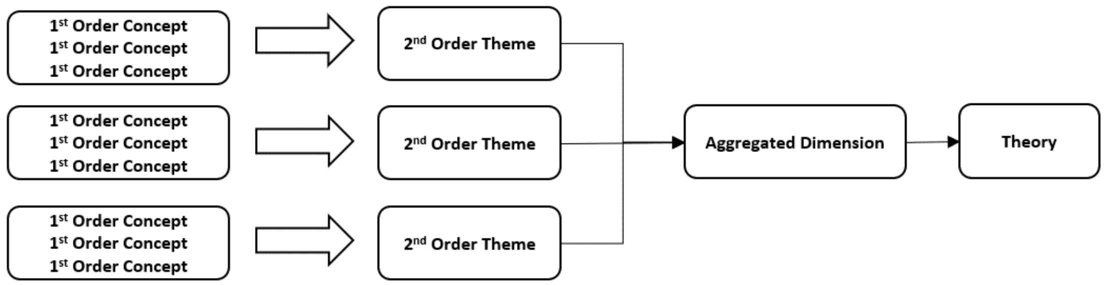

Figure 20: An illustration of the 3 steps in the Gioia methodology(Gioia et al., 2013). The Aggregated Dimension will be connected to the theory in the discussion chapter

The third and last purpose of the analysis is to tie the 2nd Order Themes with the theory in an Aggregated Dimension. By doing this, the concepts from the interview are structured and easier to grasp. The data structure will be the foundation for the discussion in chapter 8, where the Aggregated Dimension will be linked up against the conceptual framework. The structuring of the data is made of concepts and themes that share the same theory as an Aggregate Dimension in the same table.

An example of the Gioia methodology used in the conducted interviews is listed in table 21 on the next page. First, several 1st Order Concepts were observed. Some of the 1st Order Concepts concerned the same topic, and therefore they are listed together. An example of this is displayed in reg. 5.1., where two 1st Order Concepts by AQS concern the same 2nd Order theme. "AQS must reduce emissions by 40% by 2026" and "AQS shall secure low-emission shipping to its customers" are both in the same 2nd Order Theme of "Change in business strategy". Furthermore, there are 1st Order Concepts from OHC and TE which share the same 2nd Order Theme.

In this way, several 2nd Order Themes are identified based on many 1st Order Concepts. The next step is to determine the Aggregated Dimension based on the 2nd Order Themes. It is done by looking at the themes from above and drawing on the theoretical insights. In table 21 five 2nd Order Themes have been identified; changes in business strategy, streamlining actors through integration, fear of path dependencies, creation of inter-dependencies as a risk-mitigating mechanism, and creation of willingness to invest. All these 2nd Order Themes share the same Aggregated Dimension of "Timing and adoption chain alignment".

Ref.	1. Order Concepts			2. Order Themes	Aggregated dimensions	Theory
	AQS	OHC	TE			
5.1	- AQS must reduce emissions by 40\% by 2026 - AQS shall secure low-emission shipping to its customers - AQS must live up to future regulations on CO2	- OHC supports companies in taking decisions towards investing in hydrogen	- TE shall have a considerable market share of green hydrogen production before 2030	**Change in business strategy**	**Timing and adoption chain alignment**	**The Value Blueprint by Adner (2012)**
5.2	- The supply of green hydrogen is the most important criterion for AQS to invest in hydrogen	- Integration of the SC actors are important - Collaboration between every actor is essential for better integration of technologies	-Timing the supply with the demand is an important criterion - The different SC actors' knowledge does not overlap, and it is, therefore, important to collaborate so the integration of the different industries takes place correctly	**Streamline actors through integration**		
5.3	- There is a high cost in shifting to new technologies	-It is difficult to choose a path when the members do not know which to follow	- Accept that the first investment in technologies will be outdated in some years and it thus requires investment in new technologies	**Fear of path dependencies**		
5.4	- Contracts with customers that lead to risk sharing can be a way of mitigating risk - The risk shall be spread out to co-innovators with the use of the sustainable alliance	- Contracts with customers that lead to risk sharing can be a way of mitigating risk	- If the project does not get support from ENOVA, contracts will be an important tool for realising the project - The risk needs to be spread out among SC actors	**Interdependency as risk mitigating mechanism**		
5.5	- There is a need for everyone to start investing - We dare to invest	- We must be willing to invest, and we must start investing now. - How hard we push to have something to say - Everyone is dependent on the different SC actors' willingness to invest and develop technology	- We must be willing to pay for the higher prices - We must be willing to invest even though there is uncertainty in technology - TE dare to invest before the market is ready and they dare to take a considerable amount of risk	**Creation of willingness to invest**		

Figure 21: The table displays the data structure with the aggregate dimension of timing and adoption chain alignment.

Where figure 21 displays the Aggregated Dimension of "Timing and adoption chain alignment", 6 other Aggregated Dimensions were also identified, described in table 3. The other Aggregated

Dimensions and their associated 1st Order Concepts and 2nd Order themes are in the following sections.

7.1.1 The aggregate dimension of innovation driven environment

Ref.	1. Order Concepts			2. Order Themes	Aggregated dimensions	Theory
	AQS	OHC	TE			
1.1	- The specific leaders and the employees form the future strategy and has a great deal to say in accelerating the industry	- The size of the company matters when daring to invest in hydrogen - There is a need for new companies that can be game-changers - Public purchasing as passenger ferries and the Norwegian Armed forces help create the supplier market - Especially the manufacturing and bigger companies take the lead - A good reputation makes it easier to get other actors onboard	- A couple of actors have begun to form the path which has resulted in many followers - A first-mover advantage can result in winning market share and being more competitive in the future - There is a risk of being a first mover, but also an opportunity	**Power to influence**	**Timing and ecosystem participation**	**MIT stakeholder Framework by Budden and Murray (2019)** **The wide lens, Adner (2012)**
1.2	-There are different paces, and some companies are ahead of others. - Some are more willing to risk, and some have at greater focus on sustainable solutions.	- Much has happened, and much will happen, which creates high uncertainty for future pace - The actors have different paces - The mindset of the maritime sector is a barrier, because they are used to be told which path to take	-Timing the supply with the demand is an important aspect - Many actors are laid-back and waiting for others to take the steps - Many actors are interested but wait until the market is more developed to mitigate risk	**The pace of the industry**		
1.3	-AQS are very dependent on other actors since every process requires collaboration	- There is a need for collaboration, however, no one is sitting on the top and guiding, and joint ventures are not necessarily collaborating - Collaboration is needed when risk is high, we must work together to reduce the individual risk - We must start testing since pilot project are very important to drive the development of technology and supply chain	- Every important actor needs to be on board to solve problems parallel -We need to start pilot projects with the right actors around the table - Collaboration with all actors is needed to solve the issues even with competitors - Interdisciplinary know-how is needed in the development of the supply chain - There is a need for creating standard solutions with other actors	**Co-innovators dependencies**		

Figure 22: The table displays the data structure with the aggregate dimension of innovation driven environment

7.1.2 The aggregate dimension of Innovation type limitations

Ref.	1. Order Concepts			2. Order Themes	Aggregated dimensions	Theory
	AQS	OHC	TE			
2.1	- The goals shall be reached through sustainable alliances. - The first investments in technology and a certain area shall be considered carefully - We shall hurry slowly.		- We need to invest in a new way with more uncertainty to get actors on board	**Change in processes to reach the goals**	**Innovation type limitations**	**M. Henderson and Clark (1990)**
2.2			- TE can use their capabilities from power production and electrification experience	**Capability use**		

Figure 23: The table displays the data structure with the aggregate dimension of architectural innovation limitations

7.1.3 The aggregate dimension issue/solution alignment

Ref.	1. Order Concepts			2. Order Themes	Aggregated dimensions	Theory
	AQS	OHC	TE			
3.1			- It is important to have in mind that different actors have different needs ex regarding the container swapping	**The acknowledge of different needs**	**Issue/solution alignment**	**Issue/solution matrix by Andersen et al. (2018)**
3.2	- Investing in hydrogen shall be a sustainable business case	- The sustainable strategy must be other than an addition to the strategy - Members must be competitive in the future too	- Investing in hydrogen must be a sustainable business case - Healthy financial conditions can solve every barrier	**Sustainability in the business case (ahead of philanthropy)**		
3.3	- Investing in a solution where the demand and supply are locked to a certain area can mitigate risk		- Place the production in the right place to avoid long distribution channels of hydrogen	**The background for decision making**		
3.4	- AQS are interested in green hydrogen because they want to stop climate changes, and this shall be done through green alternatives - Over the past years request for fossil-free fuels has become greater. - AQS are only considering hydrogen	- OHC view hydrogen-fuels as a central element in future maritime fuels.	- TE have observed an opportunity in future maritime demand, which they want to exploit	**Redefine future strategy**		

Figure 24: The table displays the data structure with the aggregate dimension issue/solution alignment.

7.1.4 The aggregate dimension of adoption chain alignment

Ref.	1. Order Concepts			2. Order Themes	Aggregated dimensions	Theory
	AQS	OHC	TE			
4.1	- The crew needs to learn and adapt to the technology and does currently not have the competencies and capabilities which can be a hidden barrier	- The maritime environment is tough - We do not know how the technology will operate in the maritime environment - It is unknown how the passengers and the crew will react to hydrogen, and this can be a hidden barrier	- The maritime environment is demanding and harsh for the technology - Safety is an issue, we have not seen proof of the technology yet	**Stakeholders perceived expectations**	**Adoption chain alignment**	**Adoption chain risk by Adner (2012)**
4.2		- Hydrogen must be 100% safe to handle, and there is uncertainty in how this will be managed	- Safety risk, we have not seen proof of safely managing the SC of hydrogen	**Public approved technologies**		
4.3	- The entire SC must accept price rises - Every actor in all the sectors needs to be sustainable, so it is not just the maritime sector that needs to invest	- The entire supply chain must accept price rises - Parallel development with production and infrastructure - There is high uncertainty in future price uncertainties	The cost of hydrogen is high, and it shall be excepted by all actors	**Consensus in the supply chain**		

Figure 25: The table displays the data structure with the aggregate dimension of adoption chain alignment.

7.1.5 The aggregate dimension of timing and adoption chain alignment

Ref.	1. Order Concepts			2. Order Themes	Aggregated dimensions	Theory
	AQS	OHC	TE			
5.1	- AQS must reduce emissions by 40\% by 2026 - AQS shall secure low-emission shipping to its customers - AQS must live up to future regulations on CO2	- OHC supports companies in taking decisions towards investing in hydrogen	- TE shall have a considerable market share of green hydrogen production before 2030	**Change in business strategy**	**Timing and adoption chain alignment**	**The Value Blueprint by Adner (2012)**
5.2	- The supply of green hydrogen is the most important criterion for AQS to invest in hydrogen	- Integration of the SC actors are important - Collaboration between every actor is essential for better integration of technologies	-Timing the supply with the demand is an important criterion - The different SC actors' knowledge does not overlap, and it is, therefore, important to collaborate so the integration of the different industries takes place correctly	**Streamline actors through integration**		
5.3	- There is a high cost in shifting to new technologies	-It is difficult to choose a path when the members do not know which to follow	- Accept that the first investment in technologies will be outdated in some years and it thus requires investment in new technologies	**Fear of path dependencies**		
5.4	- Contracts with customers that lead to risk sharing can be a way of mitigating risk - The risk shall be spread out to co-innovators with the use of the sustainable alliance	- Contracts with customers that lead to risk sharing can be a way of mitigating risk	- If the project does not get support from ENOVA, contracts will be an important tool for realising the project - The risk needs to be spread out among SC actors	**Interdependency as risk mitigating mechanism**		
5.5	- There is a need for everyone to start investing - We dare to invest	- We must be willing to invest, and we must start investing now. - How hard we push to have something to say - Everyone is dependent on the different SC actors' willingness to invest and develop technology	- We must be willing to pay for the higher prices - We must be willing to invest even though there is uncertainty in technology - TE dare to invest before the market is ready and they dare to take a considerable amount of risk	**Creation of willingness to invest**		

Figure 26: The table displays the data structure with the aggregate dimension of timing and adoption chain alignment.

7.1.6 The aggregate dimension of timing and co-innovation alignment

Ref.	1. Order Concepts			2. Order Themes	Aggregated dimensions	Theory
	AQS	OHC	TE			
6.1	- CO2 taxes can boost green investment initiatives - Sustainable classifications system for groceries can be a way to make the different alternatives transparent - Media attention has helped in creating the hype hydrogen needs. - Political engagement is important for companies to invest in hydrogen - There has been a bigger interest in hydrogen the latest years, due to stricter rules which require more sustainable operations - In the latest years there has been a shift in the public mindset regarding the environment and toward sustainable solutions	- Upscale hydrogen production to get prices down - Export can create an economy of scale - ENOVA application creates more certainty, ex on investment cost - Subsidies and support from the government, ex difference contracts, can strengthen green investments - The pressure on the maritime sector is still not high enough - Price rises in oil and gas due to the war in Ukraine can result in a bigger interest in alternative fuels - Public purchasing as passenger ferries and the Norwegian Armed forces help create the supplier market	- There is a need for more pressure from the government - Due to the early phase hydrogen is in, the focus should be on supplier market development for the SC to function - CO2 taxes will create incitement for investing in green alternatives - Public purchasing in green alternatives creates a demand that needs to be met with supply initiatives - TE sees a pattern in actors related to public purchasing are ahead of others - Subsidies and support from the government, ex difference contracts, are needed	**Market creation**	**Timing and co-innovation alignment**	**The Value Blueprint by Adner (2012)**
6.2	- Fuel-cell technology is not on the highest TRL level - The readiness level of hydrogen technology for the maritime sector	First production is scheduled for 2026 but can happen before since some pilot projects already will be launched in 2023.	- There is high uncertainty in future technology and in every aspect of the supply chain - Container swap is an unproven technology and a temporary solution	**Uncertainty in technology readiness level**		
6.3	- The supply of green hydrogen is urgent	-Some infrastructure and distribution system exist but are not integrated, and this needs to be finally developed -The members have different criteria for making them invest, and it is related to the chicken and the egg issue; production companies need demand, and customers need a supply	- Bunkering, infrastructure, and distribution are not developed - Bunkering facilities need to be developed since it affects the rest of the infrastructure - It is urgent to develop the distribution system	**Missing links in the supply chain**		
6.4	- There is a low round-trip efficiency for hydrogen technology - 100\% hydrogen seems too inflexible at the current stage - AQS must be able to rely 100\% on the equipment. - We shall not depend only on one technology. - All possible solutions should be in the game	- There are not many other alternatives than hydrogen fuels when phasing out fossil fuels in the maritime - The distribution of hydrogen is difficult because hydrogen is light and very expensive to distribute. But there are companies that have developed successful technologies, so these will have to be implemented and commercialized.	- Risk of choosing the wrong technology - Uncertainty on technology lifespan and solution	**The role of the technology development**		

Figure 27: The table displays the first part of the data structure with the aggregate dimension of timing and co-innovation alignment.

7.1.7 The aggregate dimension of timing and co-innovation alignment

Ref.	1. Order Concepts			2. Order Themes	Aggregated dimensions	Theory
	AQS	OHC	TE			
6.5	- There is much uncertainty concerning hydrogen, and therefore it must be managed by taking the decisions that create the best circumstances for managing future challenges and changes to the project	- We must be honest about the future and the uncertainties	- The market does not exist - There is uncertainty in every aspect of the supply chain	**Awareness of uncertainty**	**Timing and co-innovator alignment**	**The Value Blueprint by Ron Adner (2012)**
6.6	- Mitigation of risk can be done through flexible technology, ex engines - Dual-fuel engines create flexibility in the supply chain - We should not take diesel 100% out of the equation - Innovation projects are time demanding, and it creates a need for the technology to be flexible	- Begin investing in the right segment – support systems and auxiliary engines, let it stay flexible The equipment needs to be built for the uncertainty (all members agree on this)		**Supply chain flexibility**		
6.7	- Regulation must be developed - It is urgent that the government make the legislation ready	- There is uncertainty in future requirements and regulations - Government subsidies and support are needed	- There is uncertainty in future regulations, and it is urgent to make it ready - Because of the early stage of the market, TE is dependent on government support to begin investing	**Needed government direction**		
6.8	- Classification systems must be developed	- Classification systems must be developed	- Classification systems must be developed	**The role of the institutions**		
6.9	- The development of technology is not an issue; it will be solved.	- The development of the technology is not an issue, it will be solved - Production is not difficult so it is not an issue– (large scale?) - Production is scheduled for 2026, but can happen before (are the rest of SC ready?)	- Production is piece of cake	**Perception of technology development**		
6.10	- New operations require new responsibilities, ex bunkering, which can be a hidden barrier	- There can be technology gaps that we are not aware of	- It is uncertain how the bunkering of hydrogen will take place	**Unrealized missing links**		

Figure 28: The table displays the second part of the data structure with the aggregate dimension of timing and co-innovation alignment.

7.1.8 The aggregate dimension of co-innovation alignment

Ref.	1. Order Concepts			2. Order Themes	Aggregated dimensions	Theory
	AQS	OHC	TE			
7.1	- AQS are in the game and see themselves as an actor who takes the lead. - They are a company that is proactive	- The role of OHC is to support members and give them an overview of the industry and make invisible aspects visible - OHC is in the game supporting their members	- The role of TE is to become a hydrogen manufacture - TE will assist other actors with their knowledge and capabilities to promote progress - TE will work together in joint ventures for creating standard solutions - TE is in the game and has positioned itself ahead of other actors - TE must also invest in distribution and infrastructure - TE will maybe own the Container-swapping product	**Perception of actor's role**	**Co-innovation alignment**	**The Value Blueprint by Adner (2012)**
7.2	- Previously experience has shown us, that they need parachutes - We must spread the risk to customers	- LNG is comparable hydrogen in the sense of the process to introduce a new fuel.	- Battery swapping and container swapping are a bit like the case of hydrogen – battery swapping was not a success, maybe due to different interests from company to company - Entering the wind industry or water back in the day is a bit like hydrogen, but way easier than hydrogen. - Investing in hydrogen can be comparable to when we invested in the charging of electrical batteries and the roll-out of it. TE had to invest in infrastructure and solve issues along the way.	**Innovation experience**		

Figure 29: The table displays the data structure with the aggregate dimension of co-innovation alignment.

7.1.9 Part conclusion

The analysis with the use of the Gioia methodology has been useful in structuring the data from the conducted interviews. The reference numbers, for example, ref. 1.3, will be used in the section 7.2 and 7.3 when there is a reference to a statement by one of the actors. The determined Aggregated Dimension from the analysis is displayed in section 3. It will be used as starting point for the discussion in section 8.1.

Aggregated Dimensions
Innovation-driven environment
Innovation type innovation
Issue/solution alignment
Adoption chain alignment
Timing and adoption chain alignment
Timing an co-innovation alignment
Co-innovation alignment

Table 3: The identified Aggregated Dimensions

7.2 Analysis of barriers in the supply chain of the maritime industry

In this section, RQ1 will be answered and hereby stating if there is a consensus between what the academic literature and the three actors identify as barriers in the supply chain. In section 4.2 the barriers in the supply chain for compressed hydrogen in the maritime sector are identified by GL (2018), CSIRO (2021), Sintef (2020), and Bach et al. (2020). An overview of identified barriers in the literature are listed in table 6. These barriers are held up against the perception of barriers as seen by TE, AQS, and OHC. Table 4 indicates that all three actors identify the same barriers as the literature. The actors' answers relating to the barriers can be seen in appendix A. In the following, each barrier will be explained.

Identified barriers in the literature	**AQS**	**OHC**	**TE**
The maturity of hydrogen technology	X	X	X
Competing and complementing technologies	X	X	X
Classification, legitimation and regulatory gaps	X	X	X
High risk of investing	X	X	X

Table 4: Barriers identified in the academic research in table 6 versus the perceived barriers of the actors. The table shows consensus between the academic research and the actors. The three actors view on each barrier is shown in appendix A.

The maturity of hydrogen technology

GL (2018), CSIRO (2021), Sintef (2020), and Bach et al. (2020) all identify the maturity of hydrogen technology as a barrier in the supply chain. The three actors agree that the maturity of the technology is a barrier to investing in hydrogen, and it creates uncertainty for future investments. AQS mentions that for example, the fuel cell technology is not at technology readiness level(TRL) 9, and it entails that it has not been documented that the technology is fully functioning in the maritime environment. This results in a high risk of investing in hydrogen. AQS must rely 100% on their equipment. If the technology has not been proven or commercialized, they first have to wait for the launch and then prepare for some startup issues. The maturity of the hydrogen supply chain is, thus, a barrier for AQS. OHC mentions that since the design of the supply chain is uncertain, it is difficult for the maritime actors to start investing because there are so many paths to follow and not every path will take you in the right direction. OHC mentions potential hydrogen fuels; compressed hydrogen, liquefied hydrogen, LOHC, ammonia, and methanol. All these options make it difficult to predict how the supply chain will be shaped and increases the risk of investing.

Moreover, there is uncertainty about how the different technologies will be integrated. All three actors agree that this is a barrier. TE explains that there is a big need of creating standard solutions, so the different parts of the supply chain can be easily combined. TE gives the example of bunkering technology, which is not a fully developed product. At the moment they are looking into a solution where the bunkering will happen through a container swapping method, explained in section 6.1. However, in the future, this bunkering method will hopefully be replaced by a smarter and more effective solution. Standard solutions are needed in the container swapping solution, so different shipping companies can make use of containers from different manufacturers if they go to different ports. They know that some of the technologies are not long-term solutions, and the integration methods must evolve to help minimize the costs of shifting when better solutions emerge. Otherwise, it can prevent some actors from investing.

The actors also mention that there can be barriers that currently do not get much attention. They are also described in section 4.2 The actors are also concerned that some barriers do not get sufficient attention. This is for example the capabilities of the crew. The crew is not familiar with using hydrogen and hydrogen technology, and it must acquire the right capabilities to manage it. All situations regarding managing the hydrogen on a vessel must be handled by the crew, and if it does not have the right competencies, accidents can happen. This is of course vital for the crew but also the roll-out of hydrogen technologies.

Even though the actors are aware of the immature technology and see it as a barrier, AQS and OHC still believe the immature technology barrier will be managed, according to section 7.1.7, ref. 6.9. This is important that they have trust in the companies developing the technology, but if they are too optimistic on the behalf of the technology development it can result in an unrealistic view of the timing of the technology. It is therefore vital that the actors are aligned about the time frame in which the barriers will be overcome.

Competing and complementing technologies
The aspect of competing and complementing technologies is the second barrier the three actors agree on. OHC describes that flexibility is important when designing technologies. This is due to the before-mentioned paths to follow. It is uncertain which technologies and which type of fuels will earn the biggest market share. The barrier is a paradox because the technologies are both competing and complementing each other. Their technologies compete in the market, however, they are also complementing each other, since they share many of the same development considerations. Fossil-free fuels share many of the same barriers, for example, the need for renewable power and new legislation. Promoting one alternative fuel also promote others and, thus, they are complementing.

Classification, legitimisation, and regulatory gaps
The third identified barrier is the classification, legitimization, and regulatory gaps. All actors agree that the lack of legislation is a barrier to investing. For many of the technologies onboard the vessel no classification guidelines exist. Until they are in place no one can tell how the equipment and storage will be finally realized. This creates uncertainties in ship design and extends the time for delivery and classification approval. Actors that do not have the resources to manage these uncertainties will refrain from investing. The question of future government support for fossil-free fuels also creates uncertainties. The formation of example the CO2 regulations will have a huge impact on the timing of the investments in the technologies. Will it discriminate between grey, blue and green hydrogen? Will nuclear power be considered green? If some segments of the industry will receive more support, it will likely attract more investment.

High risk of investing
The last barrier identified by the articles is the general high risk of investing in hydrogen. This creates a need for developing methods to mitigate the risk. All three actors agree on this and mention the development of contracts in a manner that lets the actors split the risk between them. This could for example be a contract between a shipping company and its customer that last for an extended period. This would allow the shipping company to engage in more risky investments, and still be certain that they have customers.

7.2.1 Part conclusion

In this section the RQ1, ”identify general barriers in the supply chain for compressed hydrogen in the maritime industry” has been answered. Four categories of barriers were identified in the conducted interviews; the maturity of hydrogen technology, competing and complementing technologies, classification, legislation, regulatory gaps, and high risk of investing. It is found that there is consensus about the barriers identified by the interviewed actors and the literature. The consensus is important because it shows that the actors are aware of the landscape, and they agree that the barriers must be overcome for hydrogen to be launched as fuel. An aspect to dwell on is how they perceive the barrier of immature technology. Two of the actors do not see the development of the technologies as a big issue, and they think this will be solved. Alignment of the perceptions is necessary for aligning collaborating actors.

7.3 Analysis of one specific barrier with the use of the conceptual framework

In this section, the conceptual framework 15 from section 5.2 will be used to demonstrate how a specific barrier is understood and managed by the three actors. In the analysis, the conceptual framework is specifically used to address the dis-alignment among the actors. Other areas could also be addressed with the conceptual framework, but due to the limitation of the master thesis these topics will be addressed but not analyzed, see section 2.4 for an elaboration on the limitations to the thesis. The barrier of technology maturity has been selected as a focal point in the analysis as all three actors identify this as a critical barrier to overcome for the project to succeed. The analysis of the conceptual framework makes use of the 1st Order Concepts from section 7.1. The concepts will be referred to through the reference number on the left side of the tables, as ex ref. 1.2 and ref. 1.3 and can be found in section 7.1.

1) Identification of the project

The first step of the framework is to identify the scope of the project by defining its purpose, the relevant actors, the timeline, and the innovation type.

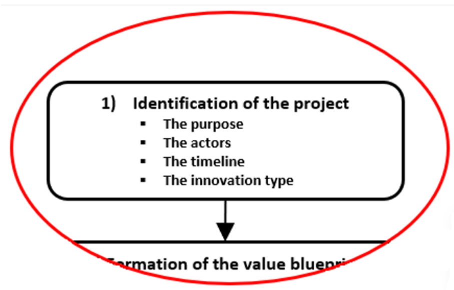

Figure 30: Step 1) of the analysis

The purpose of the project is for TE to produce hydrogen that can be bought by AQS. OHC is not directly looking into this opportunity, however, they are an organ that supports companies in making decisions related to using hydrogen as a maritime fuel. Because OHC has a high diversity of members from the entire supply chain, they possess a very useful overview of the maritime sector and know in which direction it is moving regarding alternative fuels. TE is seeking to invest in hydrogen production for the maritime sector, because it has identified a future business opportunity and wants to explore if they are capable of delivering this, according to section 7.1.3, ref. 3.4. On the other end of the supply chain is AQS. They are interested in shifting their maritime fuel to a fossil-free alternative given climate change, but also from increased interest in fossil-free fuels by the customers. Se section 7.1.3, ref. 3.4. According to section 7.1.3, ref. 3.2, TE and AQS agree that a sustainable business case is central for them to start investing in hydrogen.

The central actors in this scope are TE and AQS. TE is the manufacturer of hydrogen and AQS is the customer. OHC represents the voice of its members as described in section 6.2. Other supply chain actors worth mentioning are the power producers, suppliers of equipment, bunkering facilitators, ports, and end customers. They will be described in step 2).

The timeline is not precisely specified because the project is still on the drawing board, but the launch of hydrogen production shall take place around 2025. Both TE and AQS are interested in hydrogen getting ready as fast as possible, however, they also state that many aspects have to be lined up before this can happen. They express that determining the timing of the supply and demand is difficult and a central aspect. Se section 7.1.5, ref. 5.2. The timing will be further addressed in step 3)

The innovation type is radical according to 7. The project concerns investing in compressed green hydrogen, which does not have a fully developed supply chain. Furthermore, the actors have to invest in new technology for both producing the hydrogen and using the hydrogen on board the vessel. This implies that they also have to invest in other parts of the supply chain infrastructure. Se section 7.1.8, ref. 7.1. The innovation type is therefore defined as radical since both the product as a system and as a set of components will be radically different. Refer to M. Henderson and Clark (1990).

2) The formation of the value blueprint

The second step in the conceptual framework is to describe the landscape of the actors and the required actions. The value blueprint by Adner (2012) is used for this purpose. To form the blueprint, customers, suppliers, intermediaries, and complementors shall be identified.

The categorization of the suppliers and customers depends on the supply chain perspective taken. This description takes the perspective of TE from the supply side and AQS from the demand side.

Suppliers

- Renewable power
- Electrolysis
- Compression system
- Other equipment

Customers

- The marine farming industry
- Supermarket
- End-customer

Intermediaries

- The TSO
- Facilitator of hydrogen production
- The port

The complementors to TE and AQS are the actors they compete with to deliver the same product. However, these actors are also necessary for the development of hydrogen production. If TE and AQS want to expand their market share in the future and invest in more hydrogen vessels, they need a hydrogen infrastructure, which they cannot build by themselves. Furthermore, to get the prices down, hydrogen must shift from being niche hydrogen to being mainstream, they cannot make this happen by themselves. Thus, they have to collaborate with their competitors to expand the market, which means that they depend on their complementors to fulfill their ambitions. The collected information from steps 1) and 2) makes it possible to form the first value blueprint shown in figure 31. It displays the actors and their relations.

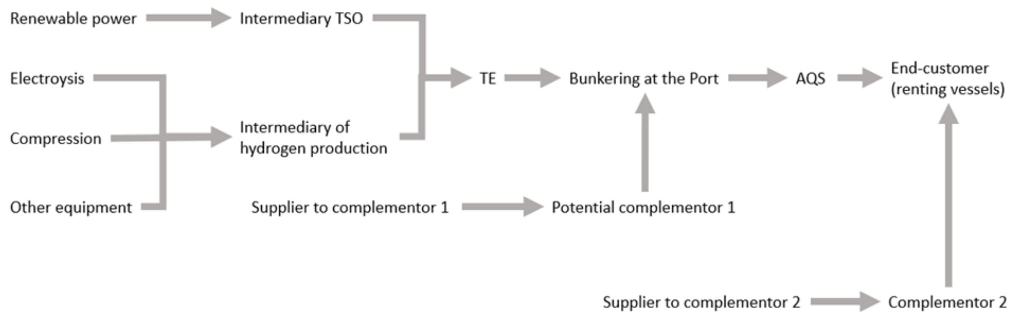

Figure 31: Formation of the first value blueprint

3) Identification of barriers in the project

In section 7.2 the general barriers in the supply chain for compressed hydrogen for the maritime sector are identified and described. All actors identify the maturity of technology as one of the biggest barriers to overcome. This leads to difficulties in choosing a path since many of the technologies do not have a TRL of 9 or a full functioning supply chain. The actors are interested in the equipment they can rely on in the harsh maritime environment. They are integrated into a fully functioning supply chain that does not get obsolete in the near future. The maturity of the technology can slow down or even stop the decision-making process due to the uncertainty that comes with it. It also makes it difficult to time the supply and demand, because it is uncertain when the equipment on both supply and demand-side is ready to operate. Alignment between all the different actors in the supply chain is required to manage the big uncertainty. In the conducted interviews the actors identify the technology innovations that must be matured for launching the project. They are listed in table 5.

Technology that must be commercialized	**Aspect to drive the innovation**
Pilot projects (1.3)	CO2 taxes (6.1)
Classification guidelines (6.8)	Media attention (6.1)
Fuel-cell technology (6.2)	Political engagement (6.1)
Flexible engines (6.6)	Regulation (6.7)
Bunkering technology (6.10)	Subsidies (6.1)
Infrastructure (6.3)	Difference contracts (6.1)
Distribution network (6.3)	Government support (6.1)
Hydrogen vessels (6.2)	Public purchasing in hydrogen (6.1)
Container swapping (6.2)	Export of hydrogen (6.1)
	Achieving economy of scale on production (6.1)

Table 5: The technology that must be in commercialized and the drivers that are critical to the increasing the speed of the development are listed. The number in parentheses points to the references in section 7.1

Even though they identify many technologies that must be mature, especially AQS and OHC describe that the technology development is not an issue. They expect current issues will be solved by the many clever heads in the companies, according to section 7.1.7, ref. 6.9. TE also states that the production is peace of cake according to section 7.1.7, ref. 6.9, but are concerned about issues such as the bunkering method and safety problems. Se section 7.1.4, ref. 4.1 and section 7.1.7, ref. 6.2. The perception of the timing element in the technology development is vital for them when entering the project. Both a pessimistic and optimistic view can result in misalignment later in the process.

Managing the barrier of technology immaturity

The identified technologies that must be commercialized -summarised in table 5- clearly display the immaturity of the total supply chain for hydrogen. For hydrogen to be boarded on a vessel, a whole chain of actions must happen as explained in section 6.1. This broadly means that the hydrogen production plant must be built and connected to the power grid. The equipment for the hydrogen production plant must be produced, set up, and fully working. Next, the hydrogen must be compressed to 350 or 700 bar. Then the bunkering method shall be determined, developed, and constructed. All these steps must happen based on classification guidelines and according to the regulations that are still not finally defined. The case is the same for vessels to be fueled by hydrogen. The vessel must be built to contain the hydrogen equipment, which requires extra space for equipment than using only diesel. This includes a fully reliable hydrogen combustion engine or fuel cell, hydrogen tanks, etc. The vessel could also be retrofitted so it can run on hydrogen. In both cases, all steps must happen based on classification guidelines and regulations.

The technologies will mature over time, but due to the urgency in solving the climate crisis and getting independent of Russian gas, TE and AQS do not want to wait too long. Their view on aspects that could drive innovation faster is illustrated in table 5. They correlated well with the drivers identified in the literature in section 4.2, figure 6. These aspects can speed up the innovation process, however, they can also slow the process down if the decisions are not ambitious enough or if they take too long to implement the initiatives. The drivers must be clarified to make the future more transparent. This will encourage the actors to invest because they are more certain about which future they invest in.

Managing risk will be less complicated when the technologies have matured, however, it will take a fair amount of time. Instead, TE and AQS can choose solutions and design their project to be less dependent on the timing of the technologies. All actors mention flexible technologies as a way of mitigating the risk of immature technology, as described in ref. 6.6 section 7.1.7. AQS mentions a dual-fuel engine. A dual-fuel engine can run on both hydrogen and diesel. This will mitigate the risk of mistiming the supply with the demand. The dual-fuel engine is described in section 6.1 step 5.

Using flexible engines will be a big advantage for AQS since they can continue operating in the transition period. However, for TE it will not fully mitigate the risk because the flexible engine secures flexibility for the consumer only. If there is a hydrogen supply but no hydrogen demand, because the hydrogen vessel is not finally approved or the technology is not ready, then they will have no off-take to their hydrogen. To avoid this situation contracts must be worked out to allow some flexibility regarding the hydrogen production and off-take.

The physics of hydrogen complicates the distribution. The low density means that it takes a lot of space and extra requirements are needed for the materials of the infrastructure because of the high pressure in storage facilities(Hafsi et al., 2018). Both TE and AQS mention in section 7.1.3, ref 3.3, that this issue can be solved by placing the products in the vicinity of the bunkering site of the vessel, thus avoiding long distribution channels. Furthermore, the vessel shall be "locked" to the chosen port so it is not dependent on hydrogen availability and bunkering facilities in other ports. In figure 5 the distribution of hydrogen is, thus, not included.

Step 4) Update the value blueprint
The value blueprint is updated with the new information regarding suppliers of hydrogen technology for the vessel. Se figure 32. The figure shows that two branches of the supply chain join where AQS is positioned. For AQS to sail on fossil-free fuels, they need a certified hydrogen vessel from its suppliers and they need hydrogen supply from TE. A bottleneck will occur if sufficient supply and demand are not in place at the same time. Solutions for eliminating the bottleneck will be a priority.

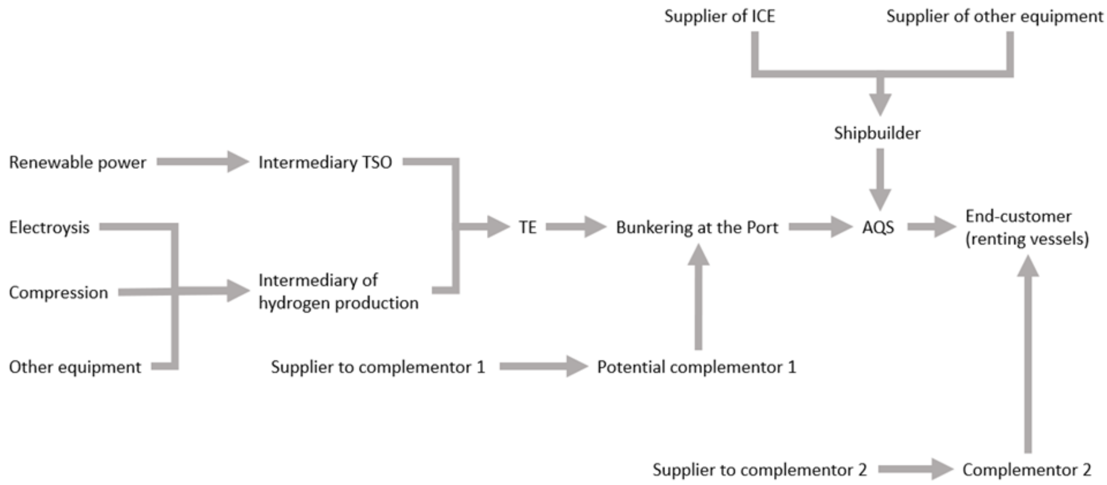

Figure 32: An updated version of the value blueprint with the suppliers of hydrogen technology for the vessel.

Step 5) Identify the risk of the ecosystem

The creation of a fully functioning hydrogen supply chain with good integration of the technologies and good timing of supply and demand requires collaboration between all participating actors. The ”innovation ecosystem” described in section 4.4 states that all kinds of stakeholders are important and that they must directly or indirectly work together and make use of each other’s capabilities, competencies, and also spillovers of resources and knowledge. Both TE, AQS, and OHC describe the collaboration between all actors as a requirement for success. TE also describes that for the project to succeed they must also collaborate with competitors, also referred to as complementors according to section 7.1.1, ref. 1.3. Collaboration in an ecosystem implies a dependency on other stakeholders. The stakeholders are collaborating but they are also competing. It is important to be aware of the risk that is present and how it can be a pitfall. In step 4), four aspects are considered: the execution risk, the co-innovation risk, the adoption chain risk, and the risk concerning innovation type and existing capabilities of the companies.

The innovation ecosystem risk is designed to understand which challenges the project faces. The innovation ecosystem risk is divided into three types; execution risk, co-innovation risk, and adoption chain risk. The focus in this scope is on the co-innovation risk and adoption chain risk.Se section 2.4. In the conducted interviews the three actors consider these risks carefully and described how mitigating them will be essential for the actors to invest in the hydrogen supply chain. The risks are listed in table 7 and will be explained in the following.

Identified adoption chain risk	**Identified co-innovation risk**
Acceptance of price rises	Perception of the timeline for technology maturity
Technology adoption by the crew	Unrealized gaps in supply chain
Acceptance by the passengers and the public	

Table 6: The adoption chain and co-innovation risks as identified by the actors

Co-innovation risk

As described in the previous section, TE and AQS are dependent on the launch of other innovation projects for their project to succeed, this is described as the co-innovation risk and explained in section 4.4.2. TE states in section 7.1.6 ref. 6.1, that due to the early phase of the hydrogen technology, there shall be an extra focus on the supplier market development for the supply chain to function. The success of the project does to a high degree rely upon the success of the supplier market of the hydrogen technology. TE will develop local production of hydrogen, but they are dependent on the innovation of the technology actors to deliver the needed equipment. TE is, thus, dependent on the innovation of the technology developers, as the technology developers are dependent on TE to build the frame of the supply chain. Co-innovation does not necessarily consist of companies innovating together on the same product, but they are dependent on other innovations for their innovation to succeed. Table 5 lists the innovation, identified by TE, AQS, and OHC, that must succeed before the project can be launched.

Mitigating the co-innovation risk will raise the odds of success. One such innovation could be flexible technology, from step 3). Another part in the supply chain where there is high uncertainty is the bunkering facilities for maritime applications. The current cascade filling technology is too slow to fill up the hydrogen tanks on board the vessel. TE emphasizes that this is a big barrier that currently has no proven solution, according to section 7.1.7, ref. 6.10. Therefore, there is a high co-innovation risk in the development of the bunkering facilities. According to section 7.1.8, ref. 7.1, a way to mitigate this risk is to invest in a temporarily bunkering solution based on known technology. TE mentions the container-swapping solution. The container-swapping solution is described in section 6.1 step 4). A better and more efficient bunkering solution is expected to be developed sometime in the future. When this happens TE must adopt the new technology.

Adoption chain risk Possible problems of timing the supply with the demand is highlighted by the three actors. For the project to succeed many actors must adopt the hydrogen technology. Both TE, AQS, and OHC mention that the entire supply chain must accept price rises in the transition from using fossil fuels to the more expensive hydrogen. This aspect constitutes an adoption chain risk because every actor in the supply chain must accept higher prices for utilizing hydrogen, according to section 7.1.4, ref. 4.3.

This risk can be mitigated through government support with modified contracts as OHC and TE mention in section 27, ref. 6.1. At the end of the day, the end customer must pay a higher price for the same product with just the difference, that it is produced sustainably. If the end customer is willing to do that, the upstream parts of the supply chain will have a business case. Otherwise, the government can support the emerging market through regulations.

Another adoption chain risk is acceptance by the crew or the passengers of hydrogen as a fuel onboard vessels. This is an aspect all actors mention in section 7.1.4, 4.1. If the crew does not feel comfortable or safe in managing the hydrogen, it can delay the adoption. This risk can be difficult to assess because, for example, future accidents can change crew and the passengers' attitudes to hydrogen.

Risk concerning the innovation type and existing capabilities

When an established firm is driving innovation, it has a lot of capabilities and knowledge it can make use of. This is in many ways an advantage. However, it can also be a disadvantage when doing innovations, because the firm is used to doing things in a certain manner and they believe this knowledge can be transferred to the innovation. This is not necessarily true. Care must be taken to avoid the existing knowledge, procedures, and capabilities getting in the way of adopting new and more comprehensive ways of doing things.

The article by M. Henderson and Clark (1990) discusses this topic. It classifies innovation as incremental, modular, architectural, or radical as shown in figure 7 in section 4.3. In this project, the innovation type is radical, because the core concepts are overturned and the linkage between core concepts and components is changed.

The radical type of this innovation calls for TE to consider the way they are working, how they understand the environment, and to carefully consider whether the ways they are doing things today will also be the right for this innovation project to succeed. The risk concerning the innovation type can be discussed concerning co-innovation and adoption-chain risk, in the sense that they from previous projects can have an opinion on how the co-innovation and adoption-chain shall be carried it. It is important to focus on these aspects. However, they can also be referred to as execution risks, which are not in the scope of this thesis as explained in section 2.4.

Step 6) Update the value blueprint
The value blueprint is updated with the information obtained on the risk in the ecosystem. "The crew" is added to the value blueprint in figure 33. The crew must accept hydrogen and feel safe when managing hydrogen onboard the vessel.

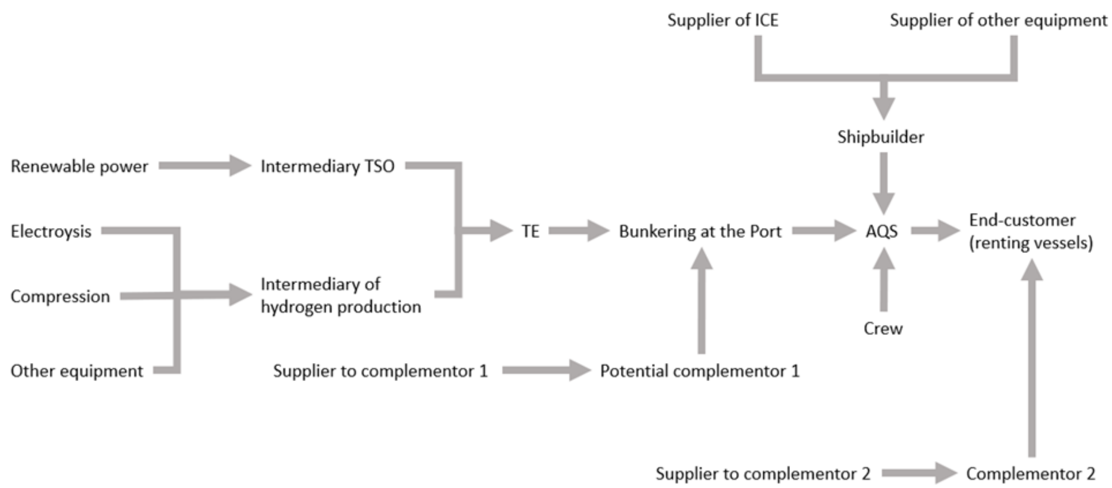

Figure 33: An updated version of the value blueprint with the suppliers of hydrogen technology for the vessel.

Step 7) Design an issue/solution matrix
In the first six steps, actors, actions, and barriers are considered. Step 7) shall take a step back and look at the issues and solutions from the perspective of other actors. Are the other actors seeing the same solution to the same issue as the focal firm? Different solutions will often solve slightly different issues and this is important to be aware of. If changes occur and a new solution is chosen it does not necessarily satisfy all involving actors. Realizing this from the beginning can free actors from future misunderstandings.

Issues (AQS)

1. AQS needs to comply to future emissions regulations, according to table 7.1.5, ref. 5.1. and contribute to stop climate changes 7.1.3, ref.3.4.
2. It is a requirement that AQS continue to rely on their equipment, and because they can not afford down-time, the solution needs to be flexible, according to section 7.1.6, ref. 6.4.
3. AQS is uncertain on how the crew of the vessels will welcome hydrogen onboard the ships

Issues (TE)

4. TE will take the role of hydrogen manufacturer and is dependent on getting the hydrogen to the market. They, thus, need to solve the issues with infrastructure and bunkering, according to section 7.1.8, ref. 7.1.
5. TE needs a demand to restart their hydrogen production, this implies that downstream actors need to begin investing

Solutions (AQS)

1. Choose the dual-fuel ICE 7.1.6 ref. 6.6
2. Choose fuel cell for applying 100% hydrogen 28 ref. 6.4

Solutions (TE)

3. The solution must be a sustainable business case, according to table 7.1.3, ref. 3.2

The issues and solutions are listed above. They have been concerted into the issue/solution matrix displayed in figure 34, and the theory behind it is described in section 4.4.5. The matrix shows that TE and AQS have different issues related to the time the supply and demand of hydrogen. However, it also shows that a flexible engine solves several of the issues.

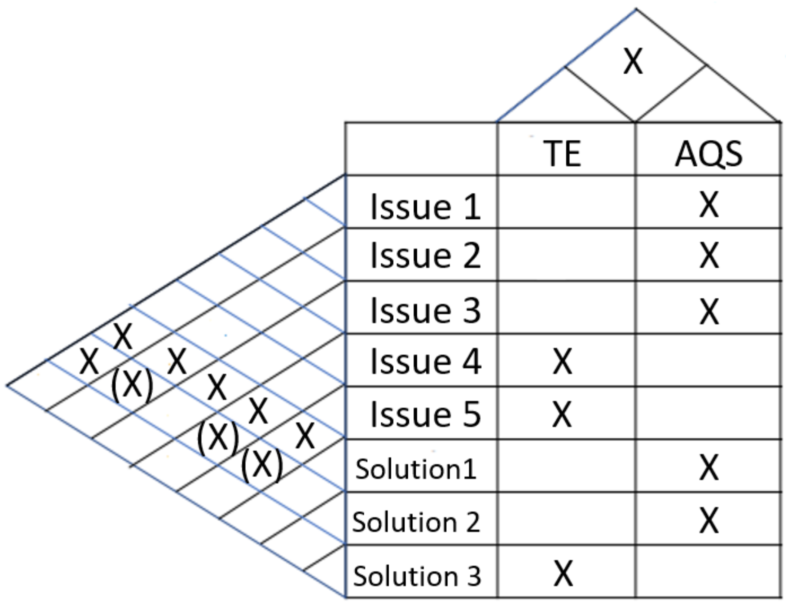

Figure 34: The issue/solution matrix in use based on the issues and solutions identified.

Step 8) Update the value blueprint with traffic lights

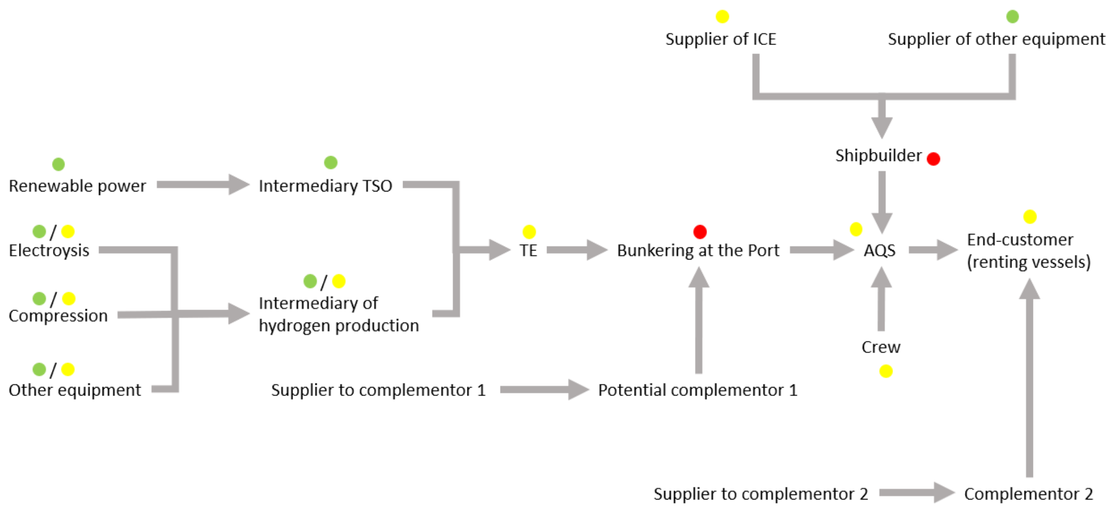

Figure 35: An updated version of the value blueprint with the suppliers of hydrogen technology for the vessel.

Based on the information from previous steps the value blueprint is updated with traffic lights that represent whether or not there is an obstacle related to the supply chain actors. The lights are described in section 4.4. The color of the light is determined based on the knowledge obtained during the writing of this master thesis, thus, the actors can view it differently.

Renewable Power and Intermediary TSO: It is expected that excess renewable power will be available in the area of hydrogen production. Furthermore, the distance to the transmission grid from where the hydrogen production facilities will be located is not long and is thus expected not to be an obstacle.

Electrolysis: The electrolysis technology is at TRL9, which means that the technology is commercialized. Time of delivery could be an issue due to a general increasing demand for electrolyzers.

Compression: The hydrogen has to be compressed to 350 or 700 bar. The TRL is 9 for the compression technology at this stage if there are no requirements for fast compression as is the case in the bunkering facilities.

Intermediary of hydrogen production: An intermediary will likely be used to organize the purchasing of the hydrogen facilities and equipment. The technology is at a TRL9 level, and as with the electrolyzers, the time of delivery could be an issue due to a general high demand for hydrogen facilities.

TE: TE is deeply optimistic and engaged in hydrogen, and sees itself as a hydrogen manufacturer in the future. However, without support at the early stage of the hydrogen market, it will be difficult for them to make a sustainable business case. Therefore, their light is yellow. However, the timing of the project will depend on support from funds or the government.

Bunkering at the port: Bunkering technology is perceived as one of the biggest issues. Hydrogen is a very light gas that has to be compressed to between 350 and 700 bar to reduce storage space. When bunkering takes place from the port to the vessel, it is a time-consuming process. The container swapping technology, as described in section 6.1, could be a way to solve the issue in the short term. However, it is expected that another solution will emerge in the long term.

AQS: AQS is willing to invest in hydrogen vessels if they, through a sustainable alliance, get a guarantee of hydrogen supply and also that their customers are willing to pay extra for renting the boat and the product they sell. The light is yellow because it requires TE to supply the hydrogen and the uncertainties about customer acceptance.

The crew: Acceptance of hydrogen onboard the vessel by the crew is uncertain and AQS is concerned about this. It can be difficult to test this aspect out beforehand.

The shipbuilder, supplier of ICE, and other equipment: The light for the supplier of ICE and the shipbuilder is red because the regulations and classification guidelines are not developed. This result is uncertainty about construction and delivery time.

End-customer: The last factor to consider in the value blueprint is the end customer. In this case, it is the customer who rents the vessel from AQS. However, they also have customers, who again have customers. The aspect to consider is if the end customers will pay extra to get fossil-free vessels.

7.3.1 Part conclusion

Applying the conceptual framework to the case gives insight into the landscape the actors are operating in. The landscape is characterized by a very great opportunity for actors if they succeed in delivering and timing the supply and demand. TE will be in the game of capturing an even bigger market share, and AQS can sell zero-carbon shipping to their customer. However, the landscape is also characterized by the many barriers that create big uncertainties the actors have to be managed when deciding where to invest. It shows that solutions that can mitigate the co-innovation risk will be beneficial for creating more willingness to invest. The dual-fuel ICE is seen as an interesting solution to the issue of timing the supply and demand. Furthermore, it adds questions on how crew and passengers are going to view and adopt the technologies. The added risk is difficult to assess, however it is an important element to consider in the design of the technologies and integration into the supply chain.

Only a few adoption chain actors and co-innovators were considered and the value blueprint was on its way to becoming complex. Applying the conceptual framework with all its co-innovators and adoption chain actors is expected to be difficult with the use of only the value blueprint for displaying the circumstances. Furthermore, the conceptual framework was not adequate in terms of defining the ecosystem actors and creating the full overview as was expected. This will be further discussed in section 8.2.

8 Discussion

In this section, RQ3 will be answered through a discussion of innovation ecosystem theory as a tool for supply chain actors to manage the specified barrier and mitigate the risk of dis-alignment. The discussion will be divided into two sections. The first discussion in section 8.1 will be based on the Gioia methodology used in the conducted interviews from section 7.1. It will be discussed how the theory relates to the Aggregated dimensions. Next, there will be a discussion in section 8.2, where the findings from section 8.1 will be related to the applied conceptual framework from section 7.3. It will discuss the applicability of theory for the actors to managing barriers and mitigating the risk of dis-alignment.

8.1 Discussion based on the Aggregated Dimensions

The structure of the discussion is shown in figure 36. The 1st Order Concepts from the analysis in section 7.1 are linked to a 2nd Order Theme that explains what the 1st Order Concept is describing. Finally, the 2nd Order Theme will be connected to the theory through an Aggregated Dimension, which explains how the 2nd Order Theme will be aligned with the theory.

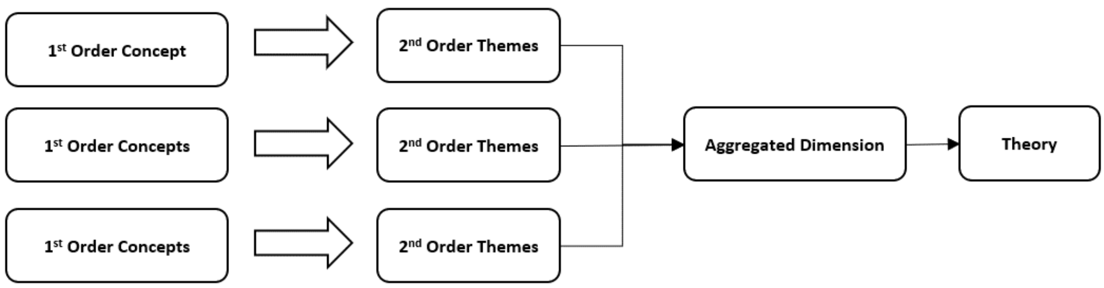

Figure 36: The figure displays the structure of the discussion.

The discussion will be structured in the following sections based on the Aggregated Dimensions determined in section 7.1 as illustrated in table 7.

Aggregated Dimensions	Associated theory
Innovation-driven environment	MIT stakeholder framework by Budden and Murray (2019) Adner (2012)
Innovation type innovation	The innovation type by M. Henderson and Clark (1990)
Issue/solution alignment	Issue/solution matrix by Andersen et al. (2018) Adner (2012)
Adoption chain alignment	Adoption chain risk by Adner (2012)
Co-innovation alignment	Co-innovation risk by Adner (2012)
Timing and adoption chain alignment	The value blueprint by Adner (2012)
Timing an co-innovation alignment	The value blueprint by Adner (2012)

Table 7: The Aggregated Dimensions and associated theory

8.1.1 Timing and drive of ecosystem stakeholders / Timing and ecosystem participants

In this section, the Aggregated Dimension of Timing and ecosystem participants will be discussed. The references for 1st Order Concepts can be seen in section 7.1.1. The three 2nd Order Themes; Power to influence, The pace of the industry, and Co-innovation dependencies have been observed related to the Aggregated Dimension of Timing and ecosystem participants.

The actors have observed that some companies have more influence and a higher pace than others, according to ref. 1.1 and 1.2. They see a pattern in many bigger manufacturing companies taking a lead and having a high pace. They also mention aspects such as the company's reputation and the presence of leaders and employees who are proactive and have a public voice. It is easier for other actors to start collaborating with well-established companies. Furthermore, according to ref. 1.3 all actors express that they are dependent on all the other actors in the supply chain. There is a need for everyone participating to solve the issues in parallel. OHC also mentions that there is a need for new companies that can help accelerate innovation.

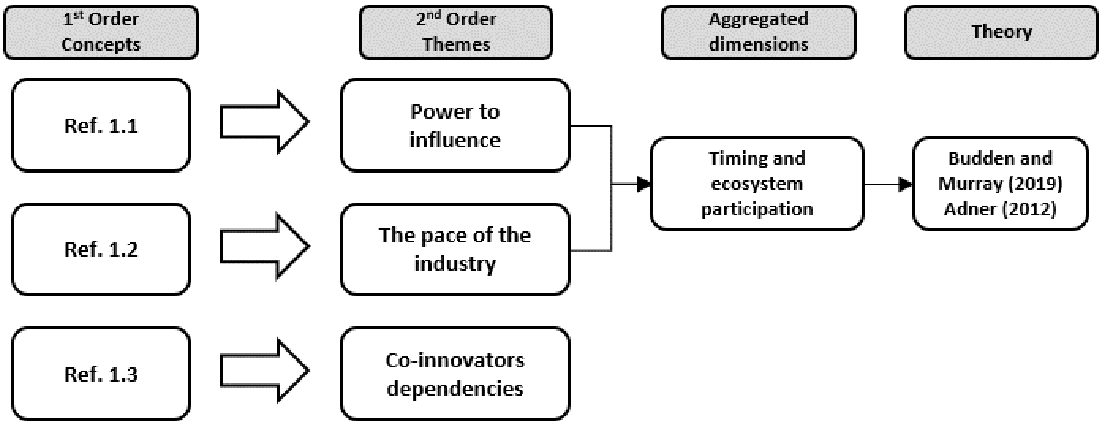

Figure 37: The figure displays the discussion of the Aggregated Dimension of Ecosystem participants. See section 7.1.1 for the entire analysis with 1st Order Concepts.

OHC gave an example of how Tesla was a game-changer for the electric car industry. This kind of game-changer is presented in the MIT stakeholder framework by Budden and Murray (2019) as an innovation-driven enterprise (IDE). Budden and Murray (2019) considers the presence of IDEs as a necessity in an innovation-driven environment. If the focal firm understands how different stakeholders contribute to the environment, they can seek this information. In an innovation ecosystem, different actors have to be present to create an optimal environment where innovation thrives. The MIT stakeholder framework presents 5 needed stakeholder groups in an innovation ecosystem; entrepreneur, risk capital, corporate, government, and university. The article seeks to support and provide advice for actors who are interested in optimizing the innovation-driven entrepreneurship within a specific region as described in section 4.4.4. It must be noted that MIT itself is the University of Massachusetts Institute of Technology, and it can be discussed if the article is biased since they believe they are a key actor. However, it is difficult not to count universities into the equation since they, by nature, create spillover with the graduation of students and by their investment in basic research.

Budden and Murray (2019) present their knowledge of how the ecosystem differs depending on which of the five stakeholders acts as the leader and which tensions exist within the different stakeholders and how their agenda affect the ecosystem.

The observations Budden and Murray (2019) have made are relevant to understanding an ecosystem and give insight into how actors can exploit the community. It, furthermore, provides advice on how interested actors can optimize innovation-driven entrepreneurship. However, it is not straight ahead to apply the MIT framework and it should also be evaluated whether stakeholders with strong power or a very great idea drive the ecosystem in a certain direction. Influencing an ecosystem requires that the rest of the ecosystem is persuaded and wants to be influenced. However, the framework is still relevant because it gives insight into the importance of different actors to the ecosystem, and this can be useful to the focal firm.

It can also be discussed how easy it is to classify the actors, ex the IDEs. The IDEs can be game-changers and have the potential to disrupt the industry. They are a necessity to drive innovation fast. But they can also disrupt the industry in undesirable ways and make it very difficult for some firms to follow.

The term ecosystem is also used in The wide lens by Adner (2012), where the focus is on managing innovation in an ecosystem. In section 4.4.4 the ecosystem and its stakeholders are defined by Adner (2006). However, Adner (2012), does not elaborate on why the ecosystem is chosen. Moore (1996) originally defines a business ecosystem as:

> "An economic community supported by a foundation of interacting organizations and individuals—the organisms of the business world. The economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders. Over time, they co-evolve their capabilities and roles and tend to align themselves with the directions set by one or more central companies. Those companies holding leadership roles may change over time, but the function of ecosystem leader is valued by the community because it enables members to move toward shared visions to align their investments, and to find mutually supportive roles."

A company is dependent on hundreds or thousands of other businesses (Iansiti and Levien, 2004). Adner (2012) seems to only deliver a weak connection to the original definition of the ecosystem. When Adner (2012) described the value blueprint as a way of mapping the ecosystem, it is essentially a map of the closest co-innovators and co-adopters rather than the entire ecosystem. It can be discussed if it is possible to map the entire ecosystem when it consists of hundreds or thousands of businesses that will change over time. To help discover the most important actors, the framework Web of relational actors by Wit and Meyer (2010) could help assist with mapping the ecosystem through its categorization of actors. It gives a great overview of the different relational actors who could influence the project, such as social-cultural actors, economic actors, political/ regulatory actors, and technological actors. It makes it possible to realize if some hidden actors potentially could play an essential role for the project to succeed.

8.1.2 Innovation type limitations

In this section, the Aggregated Dimension of Innovation type limitations will be discussed. References to 1st Order Concepts can be found in section 7.1.2. The two 2nd Order Themes: Change in processes to reach the goals and Capability use have been observed in relation to the Aggregated Dimension of Innovation type limitations. According to ref. 2.1 and 2.2, TE and AQS agree that this project requires a new way of investing due to the level of innovation and uncertainty. TE furthermore describe that they will utilize the capabilities and experience they have from power production and other innovative projects.

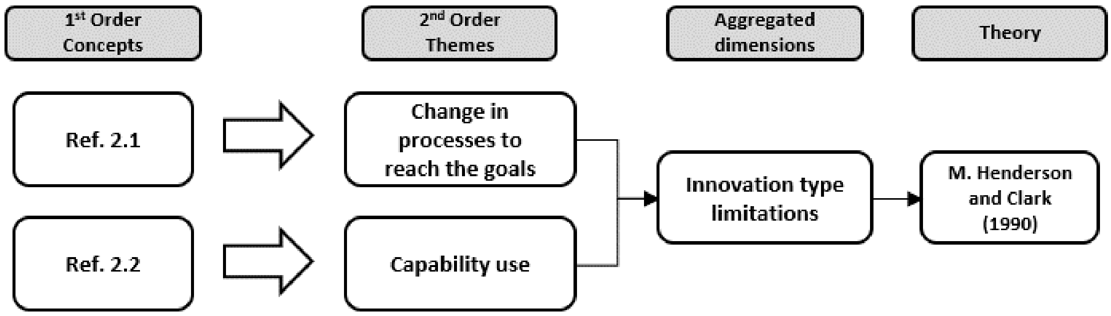

Figure 38: The figure displays the discussion of the Aggregated Dimension of Innovation type limitations. See section 7.1.2 for the entire analysis with 1st Order Concepts.

The framework by M. Henderson and Clark (1990), described in section 4.3, demonstrates that it is not necessarily an advantage for established companies to bring along their capabilities, resources, and ways of doing things. Because in practicing innovation these can be a drag rather than beneficial. The aspect of the innovation type influence, when established firms are innovating can be discussed related to co-innovation risk, adoption chain risk, and execution risk. The focus of this discussion will be on co-innovation risk and adoption chain risk. The article by M. Henderson and Clark (1990) discusses how to examine a product. A product can be viewed as a system or as a set of components. Designing a product requires knowledge about components and architectural knowledge. Figure 7 marks the difference between incremental, modular, architectural, and radical innovation. The hydrogen project will require changes to both the component knowledge and architectural knowledge which categorize it as a radical innovation. However, some of the aspects considered byM. Henderson and Clark (1990) on architectural innovation is still relevant for established companies engaging in radical innovation. Radical innovation creates huge challenges for established companies because some existing capabilities become redundant (M. Henderson and Clark, 1990, p. 13). Established firms will try to use existing capabilities when possible.

TE has knowledge and capabilities within the energy sector. But the processes or capabilities that are utilized by TE in their regular business relating to co-actors or adoption chain actors are not necessarily transferable to the hydrogen innovation project. M. Henderson and Clark (1990, p. 13) states: "Recognizing what is useful and what is not, and acquiring and applying new knowledge when necessary, may be quite difficult for an established firm because of the way knowledge-particularly architectural knowledge is organized and managed." It is, thus, worth considering for TE what is good knowledge and capabilities in certain established areas of the corporate but maybe not in innovation projects. The aspects of whether the firm is equipped to make the innovation are not considered in the value blueprint by Adner (2012).

M. Henderson and Clark (1990, p. 28) states:

> In this context, learning means learning about components and the core concepts that underlie them. Given the way, knowledge tends to be organized within the firm, learning about changes in the architecture of the product is unlikely to occur naturally. Learning about changes in architecture - about new interactions across components (and often across functional boundaries)-may therefore require explicit management and attention. But it may also be that learning about new architectures requires a different kind of organization and people with different skills.

If the focal firm realizes this early, they have the chance to change their habits and not get stuck in their path. They need to keep an eye on it. However, the articles also mention that more research is needed within this field because not all established company is alike. Some companies are more rigid than others, and TE has an innovative profile and is familiar with investing in innovative projects. TE may, thus, have the capabilities to do radical innovation. Moreover, they can be in a good position since they have experience with innovation and also have capital from the established firm, which can be an advantage when investing in radical innovation.

8.1.3 Issue/solution alignment

In this section, the Aggregated Dimension of Issue/solution alignment will be discussed. References for 1st Order Concepts are displayed in section 7.1.3. The four 2nd Order Themes; the acknowledgment of different needs, sustainability in the business case, the background for decision making, and redefining future strategy have been observed in relation to the Aggregated Dimension of issue/solution alignment. According to ref. 3.1 TE has observed that it is essential to understand and recognize that all actors have different needs and different perspectives on the project. According to ref. 3.2 TE, AQS, and OHC agree that the project must be a sustainable business case for them to enter. However, the hydrogen project will solve different issues for them.

According to ref. 3.4 TE will invest in hydrogen because they have observed a future business opportunity and because they are convinced that hydrogen will be a big part of the energy market in the future. AQS will enter because they have observed interest from customers for fossil-free fuels for climate reasons and to live up to future regulations. Each actor takes decisions to mitigate the risk in the supply chain, but inevitably also to mitigate its own risk. According to ref. 3.3, AQS is interested in locking its hydrogen vessel to a specific area, where the production of hydrogen takes place. In this way, they have secured supply. TE is also interested in that AQS locking their vessel to the area to secure the demand. However, TE is also interested in placing the production in a strategically smart place, so they can avoid long distribution channels. If TE customizes their project to fit into the business of AQS it can make it harder to change the business model later to make it fit other potential customers in the future.

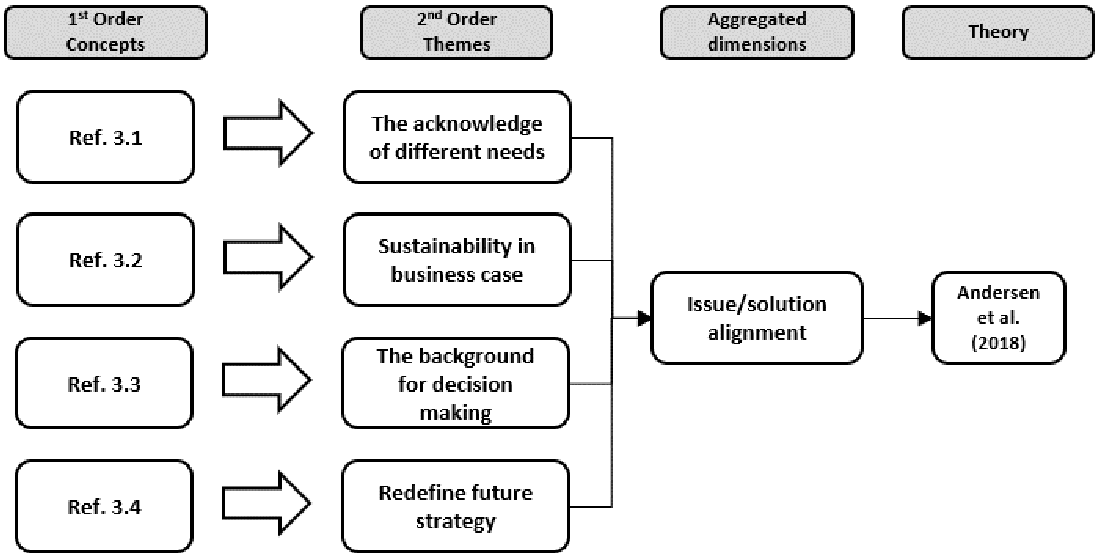

Figure 39: The figure displays the discussion of the Aggregated Dimension of Issues/solution alignment. See section 7.1.3 for the entire analysis with 1st Order Concepts.

The considerations the actors have on different issues and solutions are discussed by Andersen et al. (2018) in the framework of the issues/solution matrix. Andersen et al. (2018) states that a network of actors and their relations are changing over time affected by changes in the environment and who takes part in the network. TE and AQS have issues and solutions, however, they will also change over time. The purpose of the issue/solution matrix is to display how different actors perceive issues and solutions, furthermore, it is to realize if the picture has changed over time.

As mentioned before, The wide lens by Adner (2012) also considers the agenda of each actor and how each actor perceives the project. The task of the value blueprint is also to discover if there are hidden agendas that could affect the success of the project. However, as Andersen et al. (2018) presents, there are often several issues and also several solutions in the network. Displaying multiple issues and solutions can be difficult in the value blueprint, but here the issue/solution matrix can complement the value blueprint creating an overview of the specific issues and solutions. Based on the issue/solution matrix, a solution acceptable to all network actors can be selected and added to the value blueprint. If no single solution solves all the issues, multiple solutions can be selected, or they can be used to find new inspiration for new solutions.

8.1.4 Adoption chain alignment

In this section the Aggregated Dimension of Adoption chain alignment will be discussed. References for 1st Order Concepts are displayed in section 7.1.4.

Three 2nd Order Themes have been observed; stakeholders perceived expectations, public approved technologies, and consensus in the supply chain. The themes have in common, that even though all three actors are very interested in investing in hydrogen, they express doubts about different stakeholders' preparedness to receive and adopt hydrogen.

Ref. 4.1 and 4.2 concerns the crew and the passengers. How they will welcome hydrogen remains to be seen. The crew is used to handle the fuel MGO which is dirty, polluted, and hazardous for your skin. However, MGO is not explosive in case of leakage as is hydrogen. Furthermore, the maritime environment is harsh and it can take time to get the spare parts if the vessel is at sea. This may prove more critical when using hydrogen than MGO. The crew must learn to manage the new technology.

According to ref. 4.2, OHC and TE also express concern about the public acceptance of hydrogen. Accidents can generate insecurity and fear around hydrogen, leading to resistance and protests from the public hereby extending the application processes as it happened to wind power. Therefore, every needed safety precaution must be taken. Another aspect is how the entire supply chain will react to rising prices, as expressed in ref. 4.3. There must be an awareness by all supply chain actors that the prices will rise. This awareness must extend to the end customer to create a sustainable business case.

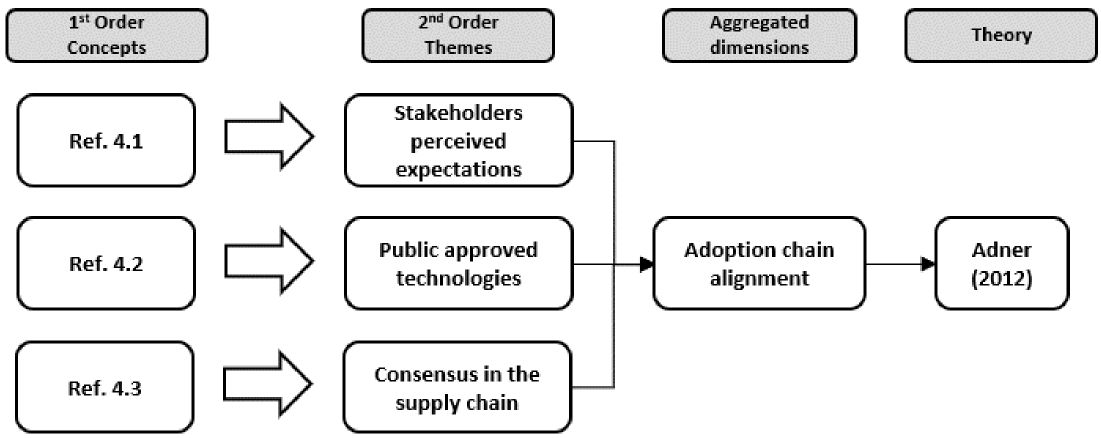

Figure 40: The figure displays the discussion of the Aggregated Dimension of Adoption chain alignment. See section 7.1.4 for the entire analysis with 1st Order Concepts.

How can the risk of dis-alignment of actors and the risk of creating a product that no one will use, be mitigated when actors have to adopt hydrogen? These are aspects that (Adner, 2012) considers. When a company performs its standard task with incremental innovation, it primarily has to consider the risk concerning the execution of a project, and to a less extent the adoption chain risk and co-innovation risk(Adner, 2012, p. 35). However, when a company is innovating in collaboration with other actors the execution risk is still present, but the adoption chain risk and the co-innovation risk become increasingly more important. These two risks tend to be overlooked, and Adner (2012) explains that overcome this, the company has to use a wider lens.

Adner (2012) assesses the adoption chain risk by having the innovator shift perspective away from its backyard to that of the intermediaries (Adner, 2012, p. 57). From the innovator's perspective, it sees the total benefit that comes with the new product while the consumer only considers the change in benefit from the old product to the new. It is the same case with the price. Where the innovator considers the purchase price, the consumer considers the total costs and risks.

At focus in Adner (2012, p. 62) is, that every actor must be considered equally important since each of them will have to adopt the innovation for the project to succeed. Thus all intermediaries must be assessed to work out whether or not they will benefit from adopting the innovation. If the answer is negative, they have no motivation to adopt the innovation and a red flag is waving. If the focal firm estimates that it is too big of a barrier to climbing for the co-actor, the innovator can either choose an alternative option or try to find a new intermediary who can gain from the innovation Adner (2012, p. 64).

Adner (2012, p. 77) emphasizes the importance of finding the solutions that cause investors to target the right place in the right way. Instead of using resources to persuade intermediaries to utilize the innovation, the issue can be viewed from the intermediaries' perspective. How can the innovation be redefined to better fit intermediaries, so they gain an advantage for adopting it? This is an important question for the focal firm to ask.

The article by Nalebuff and Brandenburger (1997) gives a checklist to the focal firm which demands it to consider the innovation from an outside-in perspective. The article is described in section 4.4.3. Nalebuff and Brandenburger (1997) wants the focal firm to do so for evaluating how the innovation can become more valuable. Not just for the focal firm, but for all the actors that have to adopt the innovation. Identifying which aspects have to be captured and created to gain more market share, could assist the value blueprint by Adner (2012) in discovering the hidden elements that are difficult to see from an inside-out perspective.

8.1.5 Timing and adoption chain alignment

In this section, the Aggregated Dimension of Timing and adoption chain alignment will be discussed. References for 1st Order Concepts are shown in section 7.1.5.

Five 2nd Order Themes have been observed: change in business strategy, streamlining actors through integration, fear of path dependencies, creation of inter-dependencies as a risk-mitigating mechanism, and creation of willingness to invest. All of them have in common, that the actors are dependent on other stakeholders' adoption of hydrogen at the right time. According to ref. 5.1 hydrogen is part of the three actors' corporate strategy. In ref. 5.2 they all emphasize that it is essential to time the supply and demand. To do this they must collaborate and be streamlined. They must collaborate on the development of technologies and integration processes because their knowledge does not necessarily overlap. TrønderEnergi has no experience operating in the maritime sector, and, thus, they must collaborate with maritime actors to understand their needs in the innovation project.

According to ref. 5.3, an aspect to consider related to adoption chain risk is the fear of path dependencies. Changing to a new fuel type has a high cost. The same is true for equipment utilized in hydrogen production. The actors have a lot at stake when investing in technology and in most cases, they can not afford to choose the wrong path. This causes the actors to hesitate until they have seen clear signs, that they are taking the right path. According to ref. 5.4 the actors also look into ways of mitigating risk. Successful mitigation can make them dare to invest and adopt the product faster. Furthermore, all actors observe in ref. 5.5, that there must be a willingness to invest to drive the innovation.

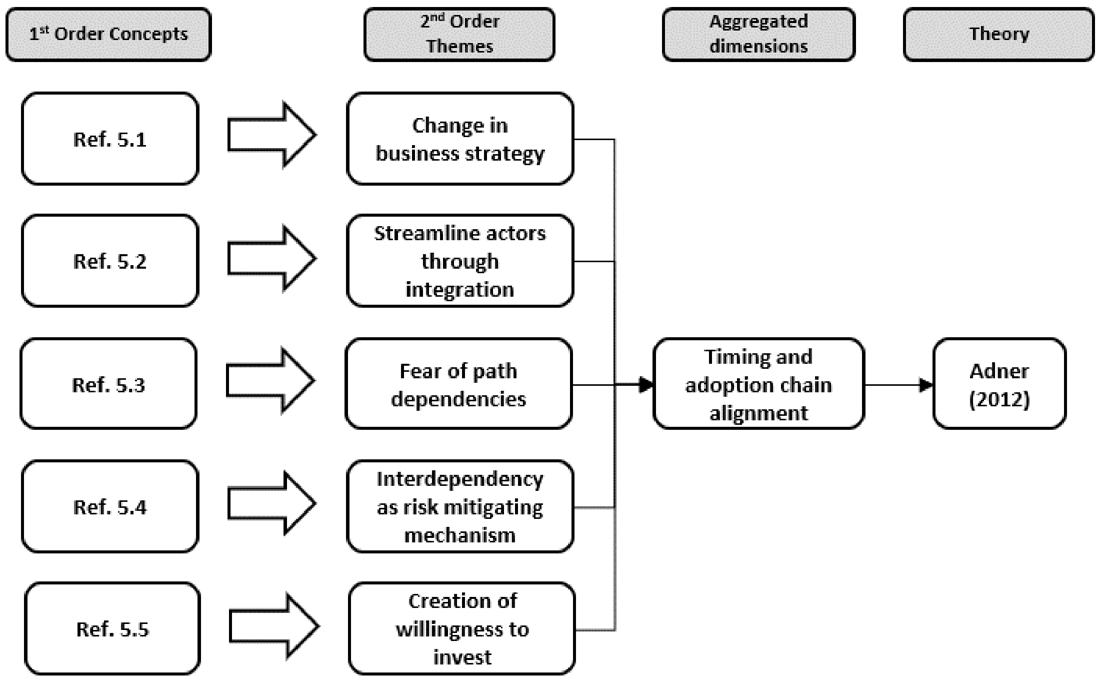

Figure 41: The figure displays the discussion of the Aggregated Dimension of Timing and adoption chain alignment. See section 7.1.5 for the entire analysis with 1st Order Concepts.

In section 8.1.4 the adoption chain alignment is discussed. In a discussion of adaption chain risk, the timing aspect is a central part of the alignment. What good is it that the focal firm is ready to launch the project if the intermediaries are far from ready? It can be assumed that some adoption chain actors do not find the innovation as beneficial as the innovator. If adoption chain actors find it riskier to join the innovation now than in five years - why invest now if you can invest later and mitigate the risk? They must have an understanding that the risk is worth taking now, and that postponing also incurs risk. This could for example be the risk of higher prices related to fossil fuels due to the war in Ukraine or the introduction of carbon taxes. If the actor believes there is a big risk of higher prices on the maritime fuel they use now, it can be beneficial to begin investing in hydrogen.

The wide lens by Adner (2012) considers the aspect of timing, but not in detail. (Adner, 2012, pp. 177–178) describes that every adoption chain link shall be addressed in advance of its launch. The adoption chain links have to be redefined by the focal firm to construct the smoothest path possible toward the end customer. This may require changes in resources and trying alternate paths. However, it is also stated that the actions should not be rushed through until fundamental dynamics are shown. Adner (2012) does not cover the timing aspect concerning the adoption chain in detail. How can actors determine the right timing when the innovator does not possess the same knowledge as the adoption chain actors? When will they decide to adopt the innovation? Are the involved actors in agreement about the timing? Do the adoption chain actors have the same stake as the innovator if the timing is not perfect? The focal firm must have an extra focus on these timing elements in relation to the actors' adoption of the innovation.

8.1.6 Co-innovation alignment

In this section, the Aggregated Dimension of Co-innovation alignment will be discussed. Reference to 1st Order Concepts is shown in section 7.1.8. The two 2nd Order Themes of perception of actor's role and learning from innovation experience have been observed concerning the Aggregated Dimension of Co-innovation alignment. TE and AQS have observed roles in the project. See ref. 7.1. Both perceive themselves as head of others in relation to the entire maritime sector. They believe they have the capabilities to succeed in the project, but only if they collaborate with others. This is a requirement to succeed. According to ref. 7.2 they have learned through experience that risk must be shared across the supply chain to raise the odds for innovation projects to succeed. Furthermore, they must also invest in parts of the supply chain where they are not currently present for the supply chain to function. But how do co-innovators secure that the risk is divided among the actors so they all have relatively the same stake and that each actor perceives its role the same as other actors do?

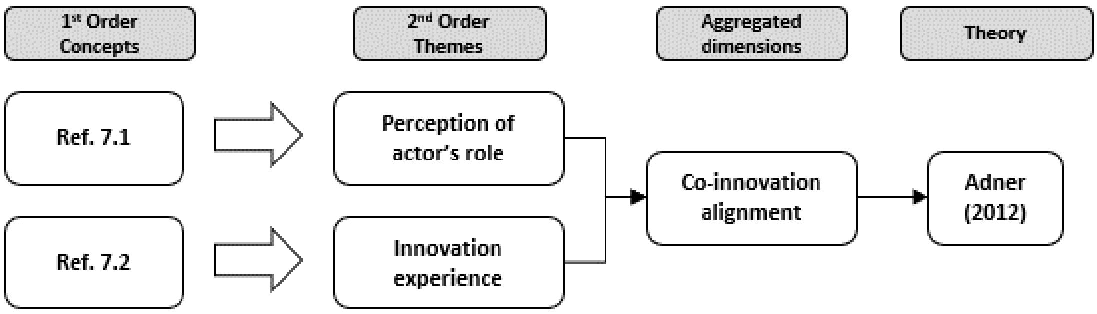

Figure 42: The figure displays the discussion of the Aggregated Dimension of Co-innovation alignment. See section 7.1.8 for the entire analysis with 1st Order Concepts.

The wide lens by Adner (2012, p. 37) covers co-innovation risk to what extent the success of the focal firm's innovation project relies on other innovation projects' success. In some cases, one participating actor depends on another co-innovator to launch an innovative project for their own to succeed. If actors are dependent on each other's innovative success, they are collaborating in raising each other's odds for success Adner (2012, p. 47).

The Adner2012 approach to the co-innovation risk is to calculate the probability of success for each co-innovation project. In The wide lens, percentages are used to calculate the risks. By adding the different co-innovation projects' probability of success, the total probability of innovation project success can be calculated. It can be discussed if this is a realistic number since it is based on intuition and assumptions about future circumstances. It may be useful for trending but not necessarily for decision-making.

Due to the difficulty in calculating the probability of success for each co-innovation project, (Adner, 2012, p. 51) suggests that a simpler assessment of risk can be more convenient. For example, use a scale of 1-5 or low/medium/high. In the case of risk, it is essential to explore the area thoroughly and take measures to mitigate it. (Adner, 2012, p. 51) emphasizes that it is not the exact number that is important, but the understanding of the accumulated probabilities. It is important not only to focus on the risk of execution of the focal firm's innovation and that the success to a large extent also depends on the strategic choices that will be made by co-innovators.

8.1.7 Timing and co-innovation alignment

In this section the Aggregated Dimension of Timing and co-innovation alignment will be discussed. References for 1st Order Concepts are displayed in section 7.1.6 and 7.1.7. Eleven 2nd Order Themes in relation to the Aggregated Dimension of Timing and co-innovation alignment have been observed and are displayed in figure 42. TE, AQS, and OHC have any thoughts related to timing and co-innovation. According to ref. 6.1-6.3 they have a big focus on the creation of a market, the uncertainty in the technology readiness level, and the missing links in the supply chain. All three actors agree that the market is not developed, TE mention that especially the supplier market must take off. Due to the immature hydrogen technology, there are several missing links in the supply chain. Such as hydrogen distribution, bunkering, and product availability.

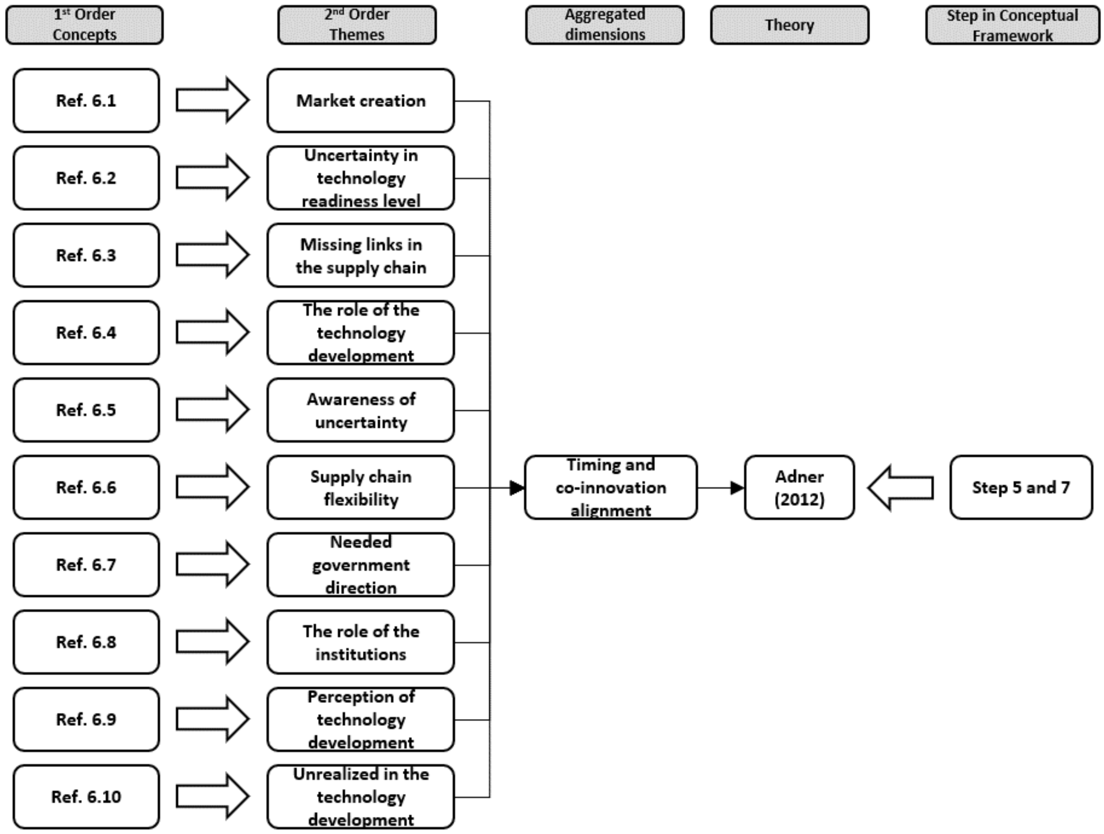

Figure 43: The figure displays the discussion of the Aggregated Dimension of Timing and co-innovation alignment. See section 7.1.6 and 7.1.7 for the entire analysis with 1st Order Concepts.

According to ref. 6.4 and 6.5 the immature technology makes the role of the technology development very central. Aligning co-innovators and timing the market is a difficult task when there with so many uncertainties in the future hydrogen supply chain. AQS makes a point of choosing technologies that makes them as flexible as possible and open to all possible solutions. This relates to ref. 6.5 where the 2nd Order Theme is "awareness of uncertainty". The uncertainty is high, TE, AQS, and OHC recognize that they must be honest about it, and not turn uncertainty into certainty.

The 2nd order theme of ref. 6.7 and 6.8 are government directions and the role of other institutions. TE, AQS, and OHC emphasize that the hydrogen industry must know which direction the regulations will take. The same goes for the classifications system that must be in place for the equipment to be approved onboard a vessel. Moreover, TE, AQS, and OHC also note how dependent everybody is on other co-innovators. Every actor that has a part in the development of the hydrogen sector must participate around the table when the classification system and regulations shall be formulated, see ref. 1.3. If a central actor or certain aspect is forgotten it can have big consequences for the timeline and can lead to delays.

The last two 2nd Order Themes are; perception of technology development and unrealized missing links. According to ref. 6.9 all three actors see hydrogen production as a simple process. Even though the actors are aligned on this matter, it can also be questioned, if this is as simple as the project, or if their attitude is influenced by the fact, that every other aspect is more uncertain. According to ref. 6.10 the actors also mention that there can be hidden barriers and gaps that have not been revealed. This is a very important aspect to be aware of since hidden barriers can stall the project.

Section 8.1.6 treats the aspect of co-innovation alignment, and as was the case with adoption chain alignment, the timing is also essential in co-innovation alignment. Co-innovators can to an extent try to time their innovation, but it is not an easy task, since each of them is dependent on a wide range of other things.

As mentioned, Adner (2012) wants innovators to consider if they are at the right place at the right time, and "under what circumstances should I be early or late?"Adner (2012, p. 140). It is, thus, up to the focal firm to consider, if the place and time are right, or if they shall wait until the future is more bright. They have to decide if there is a significant first-mover advantage. Adner and Kapoor (2010) has made a table to aid in determining if there can be a first-mover advantage. The table is divided into four categories. Table, 4.4.2 from section 4.4.2 displays the four quadrants. If the axis of "Innovator execution challenge" is high and the axis of "Complementor co-innovation challenge" is high, there is a possibility that there will be a first-mover advantage, however, it does to a wide extent depend on other challenges being resolved first.

What Adner describes as smart-mover advantages is a clever concept, but how easy is it to time the market? Adner (2012, p. 155) gives an example of the MP3 player that needed easy access to music before it could succeed. But is it easier to have hindsight than foresight? Adner (2012, p. 155) states that the innovator should dare to not rush forward and instead take the smart-mover position and strike back when the last pieces can fit into the picture. Even though this without a doubt is the smartest choice, the company must evaluate if it has to invest in the game in one way or the other to the chance to enter at the strategically right time to gain market share. This aspect is outlined (Adner, 2012).

8.1.8 Part conclusion

The discussion does to a large extent concern how The wide lens Adner (2012) and the framework The value blueprint, which is central in the developed conceptual framework, relates to the Aggregated Dimensions determined in the 7.1. It was considered if the theories could be used on the aspect that the interviewees had a focus on. It was found in the discussion that Adner (2012) that the theory behind the value blueprint could be used to get an overview of important relations of a focal firm, the challenges present, and actions needed for the actors to become aligned. However, the theory fell short when it had to go beyond the closets relations, when it had to take a timing aspect into account, and when several issues and solutions were evaluated. Other literature was consulted to discuss if it could be used to support Adner (2012) to give the depth of the analysis that was desired. This relates to the mapping of the ecosystem that was not sufficient. Adner (2012) is engaged in mapping the ecosystem, and instead, briefly focuses on the regular co-actors. However, it was concluded that he failed to deliver a method to map the ecosystem and instead delivered a method to map the closest co-actors. Budden and Murray (2019) can be used to understand the anatomy of ecosystems and this knowledge can be applied to the present focal firm ecosystem. The web of relational actors by Wit and Meyer (2010) can then be applied to get a more comprehensive understanding of the actors.

The issue/solution matrix by Andersen et al. (2018) was found to be useful in combination with the value blueprint Adner (2012). The issue/solution matrix is capable of handling many issues and solutions for a given project than can be displayed in the value blueprint. However, when a satisfying solution has been discovered in the issue/solution matrix it can be used in the value blueprint for connecting it to the entire picture.

Another aspect is the timing aspect of the adoption chain and co-innovation alignment. Connecting the timing aspect to the adoption chain alignment is of the greatest importance for a company when they must decide whether to wait to invest or jump in. Nalebuff and Brandenburger (1997) presents a checklist for identifying which aspects have to be captured and created to gain more market share. This can assist Adner (2012) in determining when the timing is right for the focal firm to know when to enter.

The last aspect that the focal firm shall consider and which is not treated by Adner (2012) is whether or not the company has the right capabilities to perform the innovation. As M. Henderson and Clark (1990) states, it is not necessarily an advantage to be an established company when doing radical innovation. The company has to settle with itself if it can filter the resource and knowledge they are used to, because successful innovation will not always benefit from old processes and resources to be reused, but requires a new mindset. This change in mindset must be acknowledged by the established company otherwise, it stalls the innovation. This can be applied in connection to the adoption chain and co-innovation risk since the established firm must be ready to evolve in the process of finding new solutions and eliminating risk.

8.2 Discussion and evaluation of the conceptual framework

In the last section 8 the theory was discussed with the use of the Aggregated Dimensions from the section 7.1. It showed that some of the theories came short when they had to consider the timing aspect. In this section, each of the steps from the conceptual framework will be examined to see where the conceptual framework is sufficient or insufficient. Figure 44 is an overview of the theories that can assist in giving an overall picture of the alignment of actors in the innovation project.

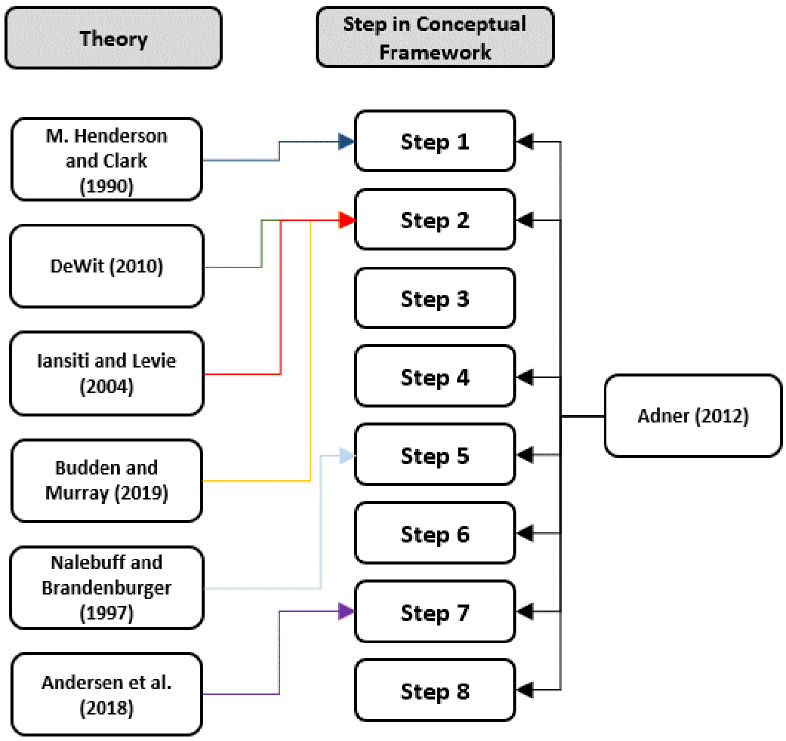

Figure 44: The figure display which theories could support each of the steps in the conceptual framework.

Step 1)

The first step of the conceptual framework consists of an identification of the project, based on needed information for constructing a value blueprint (Adner, 2012). The information gives sufficient information to understand the basic scope of the project. As extra information, the innovation type shall be identified. The reason for this is, that established companies often perceive that their resources and knowledge are an advantage when they do architectural or radical innovation, however, this can be a drag if they continue using their usual practices, as described by M. Henderson and Clark (1990). There is a big risk that they unintentionally rest on one's laurels and think they can use existing capabilities even though new capabilities are needed. To be aware of this aspect already from step 1 when later examining co-innovators and adoption chain actors, can create the needed awareness to not fall through and instead discover new focus point

Step 2)

The next step consists of the first formation of the value blueprint. According to Adner (2012) the value blueprint is for mapping the ecosystems. As was discussed in section 8.1.1 the value blueprint has problems mapping a big ecosystem (tens or hundreds of actors). Only a few adoption chain actors and co-innovators can be handled by the value blueprint. Examples of co-innovators that are not present in the value blueprint in figure 35 could be the developers of classification guidelines for equipment and vessels, IMO, intermediaries of the port, complimentors to the renewable power, etc. The value blueprint in figure 35 could contain more actors than what is displayed. However, the purpose of the value blueprint is to make an overview that is easy to grasp. If the value blueprint shall contain all the relevant information the purpose of it may disappear if it becomes too complex.

The value blueprint recommends the focal firm consider customers, suppliers, intermediaries, and complementors to determine the hidden red flags. However, it does not provide a path to discovering not-so-obvious actors. This is what The web of relational actors by Wit and Meyer (2010) can assist in. It can give a deeper insight into the ecosystem actors by mapping them into 8 categories and also considering political-, technological, socio-cultural, and economic actors. This can assist the focal firm to think in paths. An even more detailed categorization is presented by Iansiti and Levien (2004), which considers all possible ecosystem companies and places them in subcategories based on the sector in which they operate. The article by Iansiti and Levien (2004) uses Microsoft as an example. The Microsoft ecosystem consists of several groups such as the system integrates, development service companies, campus resellers, etc.

Another focus the focal firm also could have is whether the right stakeholders are present in the ecosystem. This was discussed in section 8.1.1 with the MIT stakeholder framework by Budden and Murray (2019). TE states in section 7.1.1 ref. 1.3, that the right actors must be at the table when the decisions are made. This includes decisions made on the regulation level but also at a more local level. Furthermore, OHC mention in sections 7.1.1 ref. 1.3 that no single actor is sitting on top and guiding the direction of the hydrogen ecosystem. The stakeholder framework by Budden and Murray (2019) considers this and explicitly claims that the innovation-driven enterprises (IDEs) are critical to the ecosystem building because they are at the frontline of the innovation and can provide new input on what is needed to accelerate the innovation. It is useful for the focal firm to understand different actors' roles in the ecosystem, and how each of them has the power to drive the ecosystem in a certain area. This can make it easier for the focal firm to discover which path to follow. It is, however, not obvious which IDE will succeed. In the case of TE and AQS, they could for example follow an IDEs path towards investing in compressed hydrogen technology. But if in 5 it years turns out that compressed hydrogen is overtaken by methanol as a fuel, TE and AQS will find themselves in a dead-end street.

In step 2) the first value blueprint was formed. It gives an overview of the value chain. However, important actors are not considered. Amongst these are the ports, the municipality, the fish farmers, TSO, the regulatory authorities, and the classification companies. Will there be enough renewable power in the national grid when Norway, in general, has to be electrified, or is there a need for building new wind farms or hydroelectric power plants? It can take several years to get permission to plan and build, especially having in mind that there currently are delays in supply chains worldwide. (Forum, 2022).

A deeper analysis of the ecosystem actors is needed to identify hidden adoption chain actors and co-innovators. This will complicate the formation of the value blueprint due to the many actors. It can also be questioned if a single figure can contain all the information that is required for a firm to launch an innovation project to the market. Dividing the actors into smaller groups makes the ecosystem easier to comprehend. Combining the conceptual framework with another framework to divide actors into smaller groups can be a way of managing the ecosystem. If some actors need more attention they can be used in the value blueprint. The big amount of information can also be managed through several value blueprints where each has a focus area.

Step 3)
In the third step of the conceptual framework, the barriers and drivers are identified. This is based on barriers and drivers identified in the literature from section 4.2 and augmented with the barriers and drivers TE, AQS, and OHC identify in the conducted interviews. The overview gives great insight into what the actors perceive as barriers and drivers, and -as it shows they correlate well with those identified in the literature.

The literature about barriers, listed in section 4.2, gives a great insight into the barriers and drivers that exist in the hydrogen supply chain. Even though the landscape does not change from one day to the other, the view of hydrogen has changed dramatically in the last year. Thus, the literature also gets outdated fast due to the fast technological development and the increase in actors investing in the hydrogen industry. The articles are published between 2020 and 2021, and even though they are recent, some could be outdated. However, the main barriers and drivers identified are still valid.

All identified barriers should be analyzed, but due to the scope of the master thesis, only one barrier was examined, the barrier concerning the immaturity of hydrogen technology. By analyzing this aspect it became clear that flexible technology, such as a flexible engine could be a way to mitigate the risk of not timing the market, according to section 7.3. Choosing a flexible engine will make the adoption smoother. It can give actors, who are not that willing to take the risk, a better incitement to invest.

Step 4
In step 4) the value blueprint shaped in step 2) is updated with the new information. As Adner (2012) states, the formation of the value blueprint is an iterative process and every time new information surfaces it shall be updated. The new update includes the information from AQS considering flexible engines. The supplier of the internal combustion engine(ICE) and other hydrogen equipment for the vessel is displayed in the value blueprint. This is a relevant step because new information continuously has to be brought to the table and evaluated.

Step 5)
In step 5) of the conceptual framework the innovation ecosystem risks are considered. The acceptance of price rises is considered by TE, OHC, and AQS, according to section 7.1.4 ref. 4.3. It is not just the acceptance of the higher purchasing price, but the total price of changing to hydrogen technology and associated risks. "Forcing" the actors to consider who has to adopt the innovation in the initial phase of the project, creates an opportunity to make changes to the supply chain before the path is determined. All actors identify that crew and passenger acceptance and adoption of the hydrogen technology constitutes an adoption chain risk. It could be an advantage for the TE and AQS to consider it in more detail.

A deeper analysis of each adoption chain risk is needed than the one performed in step 5, section 7.3. It is anticipated that the actors possess valuable knowledge to apply to the conceptual framework that was revealed in the interview. The framework and checklist by Nalebuff and Brandenburger (1997), described in section 8.1.4 can help in understanding the co-innovation and adoption chain risk and identifying the competitors and complementors are. Nalebuff and Brandenburger (1997) describes that the focal firm must ask itself about the value of the innovation to its customers, and what has to be done to create true value for the customer. Identifying which aspects have to be captured and created to increase the value of the product and, thus, gain market share. The framework takes the outside-in perspective to discover the hidden elements that are difficult to see from an inside-out perspective.

The discussion of the Aggregated Dimensions of Timing and adoption chain alignment from section 41 revealed a lack in connecting the adoption chain risk to a timing aspec.Se The wide lens by Adner (2012). Adner (2012) manage to some degree to couple timing and co-innovation risk through the first-mover matrix. According to section 7.1.1 ref. 1.1, TE identifies that there is an expectation that the first investors potentially will gain more market share. This is an interesting view to elaborate on because their answer suggests they see themselves in quadrant 2, *Winner takes more* according to figure 10. The axis of the figure 10 Innovation execution challenges and Complementor co-innovation challenges are both high which implies they are in quadrant 4, *Depends.* The level of the first-mover advantage in this level depends on which challenges are solved first (Adner, 2012). An assessment of whether or not this is a realistic view of the future will be valuable for TE to consider carefully. A wrong interpretation of this can have big consequences since it can underestimate present challenges. Thus, it is valuable if TE succeeds in examining the entire value proposition and decides if they have to keep going or wait. This implies that step 5) is more useful if the timing aspect is considered more in relation to the adoption chain and co-innovation alignment.

Step 6)
Step 6) consists of an updated version of the value blueprint from step 4) based on the information from step 5). As in step 4), the formation of the value blueprint is an iterative process and every time new information comes to the surface it shall be updated. This time, the risk of the crew not accepting and adopting the innovation as wanted is displayed in the value blueprint.

Step 7)
In step 7) the issues and solutions for respectively TE and AQS were considered. They are used in the issue/solution matrix by Andersen et al. (2018). The matrix displayed that TE and AQS have different reasons for investing in hydrogen. It shows that if AQS chooses to invest in a flexible engine, that will make it possible to run both on hydrogen and diesel, which will solve several issues. It will solve AQS' issue of the reliability of the equipment, and it will reduce their emissions. Furthermore, AQS is unsure of how the crew will adopt the innovation. If it results in issues, AQS can continue running on diesel until the issues with the crew are solved. For TE it creates the demand they need for their business case. By choosing this path they each mitigate risk within their field.

In section 8.1.3 it was discussed how the value blueprint by Adner (2012) and the issue/solution matrix by Andersen et al. (2018) could be used to secure alignment between the actors. The value blueprint came short due to the amount of information on several issues and solutions it shall contain. In step 7) in the conceptual framework presented, the flexible engines seem to solve issues for both TE, AQS, and the crew. The issue/solution matrix could be further used with other issues that exist in the supply chain. It can clarify if the solution of using a DF-ICE still will be promising or whether it will create other issues.

Another way of giving more nuances to step 7) could be through energy models, either from academia, consultancies, or models the companies make themselves. The article by Stöckl et al.

(2021), treated in section 4.3, examines how the optimal supply chain is designed with a focus on distribution methods and type of hydrogen fuel. It also highlight the influence tariffs and taxes have on which methods will be most attractive. A question that has not been asked in the master thesis due to the limitations described in section 2.4, is whether or not compressed hydrogen is the best hydrogen fuel to invest in for TE and AQS. Other options are liquid hydrogen, LOHC, ammonia, and methanol. The article by Stöckl et al. (2021) describes the advantage which LOHC and LH2 have in front of compressed hydrogen in storage capacity. If it is expected that the hydrogen shall be stored over a longer period, compressed hydrogen is according to the article, not the first choice. However, if long cost storage is possible, compressed hydrogen will come better of. Getting these inputs can be used to question the solution TE and AQS consider the best solution. An objective perspective can involve new potential solutions, or new aspects to consider in their existing view and solution.

Step 8
The value blueprint is in step 8) once again updated and this time also with the traffic lights to display if there are concerns to consider. The figure 35 gives a clear indication of which aspects to consider and reconsider. The final version of the value blueprint is portrayed with information on where attention is needed in the value chain. It is of course just final until a new version shall be made when new information is discovered.

8.3 Part conclusion

The discussion was divided into two sections firstly) to discuss the theories and how they relate to certain Aggregated dimensions determined in the Gioia analysis of the conducted interviews. Secondly) to discuss how the theories used in the conceptual framework could be applied to understand how actors act upon perceived barriers in relation to other actors and if the conceptual framework were adequate.

The discussion of the theories took place based on the Gioia analysis of the conducted interviews. It was discovered that the main literature by Adner (2012) to a large extent can be used to get an understanding of an innovation project, its co-innovation, and adoption chain risk and display of actors' alignment. However, it was not adequate to get the desired knowledge on alignment with many different co-actors. Especially the timing aspect of the adoption-chain risk and the element of defining the ecosystem was missing. Combining the literature from the conceptual framework with other theoretical frameworks showed great potential in achieving the missing knowledge.

In the second discussion, it was discovered, that the conceptual framework could be applied to achieve knowledge of aligning co-innovators adoption chains. However, the theories used in the conceptual framework will not be sufficient in achieving the desired knowledge to the extent TE and AQS will have to use it. The conceptual framework has the purpose for The purpose of the conceptual framework is for the focal firm to get a thorough understanding of the innovation in relation to co-innovation and adoption chain risk, and how these can be managed to secure alignment. For the conceptual framework to be fully applied more information was needed on the actors and the innovation project. The extra theory was used in the discussion to challenge the conceptual framework. Figure 44 displays where the conceptual framework needs extra support. The discussion revealed a need for obtaining a greater knowledge of the ecosystem actors than the value blueprint can give.

It can be concluded that getting a comprehensive understanding of an innovation project, the central actors, its risk, and how to create alignment, is a demanding task for one framework. It requires great knowledge of each topic. However, the conceptual framework showed the potential to get the focal firm to think about paths that often can be forgotten. To take the outside-in perspective and try to see how the actors look at the benefits the innovation project gives them. Getting an understanding and knowledge from this perspective makes it possible for the focal firm to change strategy so all actors gain from the innovation. To the extent the conceptual framework was applied in the thesis, it was adequate in containing and displaying the information in the value blueprint. However, if a comprehensive analysis shall be formed, it will not be sufficient due to the simplicity of the value blueprint. Support from other frameworks or making several value blueprints will be needed.

9 Conclusion

The overall problem statement for the master thesis was to examine how actors in the compressed hydrogen supply chain act upon perceived barriers in relation to co-actors. The problem statement was broken down into three research questions. In the following, they will be answered.

RQ1: Identify general barriers in the supply chain for compressed hydrogen in the maritime sector Six areas of barriers were determined based on a literature review on barriers present in the supply chain for compressed hydrogen within the maritime sector. These were identified to be: the maturity of hydrogen technology, lack of a predictable supply chain, uncertain integration methods, competing and complementing technologies, classification, legitimation, and regulatory gaps, and general high risk. In the analysis of present barriers, there was found consensus between the literature's identified barriers and the three actors' perceived barriers. The consensus of perceived barriers in the literature and between all actors is of high importance since it indicates alignment on a well-informed foundation. This is an important starting point for future decision-making processes.

RQ2: Examine how one specific barrier is understood and managed by three actors within the supply chain of the maritime sector using the developed conceptual framework

The conceptual framework was applied to the case study for examining how actors perceive and manage the specific barrier of immature hydrogen technology. The general immaturity of the hydrogen technologies creates great uncertainties about the shape of the future. The landscape is characterized by the very great potential for hydrogen fuels, if the actors succeed in delivering and timing the supply and demand. This can lead to that TE will be in the game of capturing an even bigger market share, and AQS can sell zero-carbon shipping to their customers. However, the landscape is also characterized by the many uncertainties that come with the general immaturity of the hydrogen technologies, and what the future of hydrogen will look like is uncertain.

It was discovered that certain solutions for mitigating the co-innovation and adoption chain risk would be beneficial for creating more willingness to invest among actors. The dual-fuel internal combustion engine for vessels was mentioned as an interesting and promising solution to solve the issue of timing the supply and demand. It was discovered that the actors are unsure how the crew and passengers will accept and adopt the hydrogen technologies. This could potentially lead to a hidden barrier or in the worst case to a product that no one will use. Whether they will accept hydrogen before they have it in their hands is difficult to determine. This is an essential element to consider in the design phase of the technologies and the supply chain integrating methods.

RQ3: Discuss how the use of innovation ecosystem theory and the conceptual framework can be used by the supply chain actors to manage the specified barrier and to mitigate the risk of dis-alignment

Based on the discussion of the theories with the determined Aggregated Dimensions from the Gioia methodology, a discussion of the conceptual framework took place. The purpose of the conceptual framework is for the focal firm to get a comprehensive understanding of the innovation in relation to co-innovation and adoption chain risk, and how these can be managed to secure alignment. Due to the scope of the master thesis, the framework was not fully applied according to the limitations of the thesis. It was discovered that the theories used in the conceptual framework manage to give an overview of the hydrogen landscape, and the most relevant actors, and considered how co-actors can mitigate risk concerning co-innovation and adoption chain alignment. It showed potential to get the focal firm to think about paths that often are forgotten. To the extent the conceptual framework was applied in this master thesis, it could contain the acquired knowledge and display it in the value blueprint.

However, it is expected that the conceptual framework will not be adequate to achieve and contain the desired knowledge of aligning all co-innovators and adoption chain actors to the extent TE and AQS will have to use it.

The conceptual framework was missing aspects in relation to obtaining a greater knowledge of the ecosystem actors and creating an even bigger focus on the outside-in perspective to understand how value can be captured and created. The conceptual framework did focus on the timing element of the co-innovation and adoption chain risk, however, an even bigger focus could be beneficial to incorporate. When it comes to it, actors are highly interested in understanding when it is strategically smart to start investing in innovation. In the discussion of the thesis, extra theories were applied to challenge the conceptual framework, and these theories and frameworks could be beneficial in supporting the conceptual framework, so it can succeed to its purpose. In the next section 9.1 on recommended further work, potential changes to the conceptual framework will be described.

9.1 Further work

It was concluded that the conceptual framework can be used by a focal firm to get an overview of the innovation project, its risk related to the co-innovation and adoption chain actors, and how alignment between the actors can be managed. However, a fully comprehensive understanding of the innovation to the entire ecosystem for discovering the hidden aspects in the co-innovation and adoption chain alignment was not achieved. Four suggestions have been identified to get a more comprehensive analysis:

1. Application of the conceptual framework on more supply chain actors to obtain knowledge from other perspectives
2. Application of the conceptual framework by TrønderEnergi and AQS
3. Application of the conceptual framework together with supporting literature

The first point The conceptual framework was applied to the conducted interviews on TrønderEnergi and AQS combined with insights for Ocean Hyway Cluster. Applying the conceptual framework to other actors will result in knowledge from even more perspectives and give insights into their issues and solutions. These actors could be the port, the municipality, the fish farmer, customers, the regulatory authorities, or the classification companies. All these actors do most likely not share the same motivation for being interested in hydrogen as TrøderEnergi and AQS do. They can have other issues and solutions they are more engaged in.

The second point The second is that the undersigned only have information from the conducted interviews, and, thus, do not have the same knowledge about TrønderEnergi and AQS as they have about their own company and their know-how. It is recommended that TrønderEnergi, as well as AQS, use the conceptual framework on the innovation project from their perspective as well as with the knowledge they have on other supply chain actors.

The third point It was observed that other theories could be applied together with the conceptual framework for achieving a more comprehensive understanding of the ecosystem actors' role in the innovation project. Applying the supporting theories has not been performed in this thesis, but it is expected that they can add the missing information to the conceptual framework. However, other undiscovered literature can also be useful. It is recommended that this analysis is carried out. Four areas of the conceptual framework needed support from other theories.

I) The MIT framework by Budden and Murray (2019) and The web of relational actors by Wit and Meyer (2010) can be utilized to get a more comprehensive mapping of the ecosystem, that makes the focal firm look beyond the typical actors to examine when looking into co-innovation and adoption chain risk.

II) The timing aspect in relation to co-innovation and adoption chain risk shall be worked further on. How can they be connected in a way so companies know when to jump or when to wait? Nalebuff and Brandenburger (1997) presents a checklist for identifying which aspects have to be captured and created to gain more market share. This can potentially support discovering what must be done to raise the odds for success and for balancing risk and benefit.

III) The focus in the conceptual framework was on taking others' perspectives, however, the focal firm shall not forget to take a look at its own company. M. Henderson and Clark (1990) emphasizes the need for a focal firm to look inwards since it is not necessarily an advantage to be an established company performing radical innovation. A new mindset, new capabilities, processes, and resources are needed. Does the firm have the ability to put away the established way of doing business? Otherwise, it may be difficult to innovate. This can be applied in connection to the adoption chain and co-innovation risk since the established company must be ready for change and to find new solutions and eliminate risks.

IV) The fourth aspect that could be further worked on, concerns how the general structure of the hydrogen supply chain should look like. The conceptual framework focused on the issues and the solutions that the different co-actors have. This is still of high importance. But what does academia say about building a hydrogen supply chain? Which solutions could be the most optimal when considering building a national integrated supply chain? Shall the hydrogen production facilities be centralized or decentralized? When does it make sense to have a hydrogen piping system? When is it better to use compressed hydrogen rather than other hydrogen-based fuels such as ammonia and methanol? It would be relevant for the companies to know the academia's view on these questions.

A Identified barriers by the three actors

Barriers	AQS	OHC	TE
The maturity of hydrogen supply chain	- There is a low round-trip efficiency for hydrogen technology - 100\% hydrogen seems too inflexible at the current stage - AQS must be able to rely 100\% on the equipment. - Fuel-cell technology is not on the highest TRL level - The readiness level of hydrogen technology for the maritime sector	- There are not many other alternatives than hydrogen fuels when phasing out fossil fuels in the maritime - The distribution of hydrogen is difficult; it is light and very expensive to distribute Production is scheduled for 2026, but can happen before (are the rest of SC ready?) - Hydrogen must be 100% safe to handle, and there is uncertainty in how this will be managed	- Risk of choosing the wrong technology - Uncertainty on technology lifespan and solution - There is high uncertainty in future technology - We have not seen proof of safely managing the SC of hydrogen
Lack of predicable supply chain	- New operations require new responsibilities, ex bunkering, which can be a hidden barrier	- There can be technology gasps that we are not aware of - There is a need for collaboration, however, no one is sitting on the top and guiding, and joint ventures are not necessarily collaborating	- Container swap is an unproven technology and a temporary solution - The different SC actors' knowledge does not overlap, and it is, therefore, important to collaborate so the integration of the different industries takes place correctly - There is uncertainty in every aspect of the supply chain
Uncertain integration methods	- AQS must be able to rely 100\% on the equipment. - We shall not depend only on one technology. - All possible solutions should be in the game - 100\% hydrogen seems too inflexible at the current stage	- Integration of the SC actors are important - Collaboration between every actor is essential for better integration of technologies	- There is a need for creating standard solution standard solutions with other actors -Timing the supply with the demand is an important criterion - Interdisciplinary know-how is needed in the development of the supply chain
Competing and complementing technologies	- There is a high cost in shifting to new technologies - Mitigation of risk can be done through flexible technology, ex engines	- Begin investing in the right segment – support systems and auxiliary engines, let it stay flexible The equipment needs to be built for the uncertainty (all members agree on this)	- Accept that the first investment in technologies will be outdated in some years and it thus requires investment in new technologies
Classification, legitimation, and regulatory gaps	- Regulation must be developed - It is urgent that the government make the legislation ready	- There is uncertainty in future requirements and regulations	- There is uncertainty in future regulations - It is urgent to make the regulations ready
High risk of investing	-AQS are very dependent on other actors since every process requires collaboration - Contracts with customers that lead to risk sharing can be a way of mitigating risk	- Collaboration is needed when risk is high, we must work together to reduce the individual impact - Contracts with customers that lead to risk sharing can be a way of mitigating risk	- Accept that the first investment in technologies will be outdated in some years and it thus requires investment in new technologies - The risk needs to be spread out among SC actors
The capabilities by the crew	- The crew needs to learn and adapt to the technology and does currently not have the competencies and capabilities which can be a hidden barrier	- We do not know how the technology will operate in the maritime environment - It is unknown how the passengers and the crew will react to hydrogen, and this can be a hidden barrier (A product that no one will use – the wide lens)	- The maritime environment is demanding and harsh for the technology

Figure 45: Identified barriers by the three actors

B Prepared Interview Questions for the master thesis "Managing barriers in the supply chain for compressed hydrogen in the maritime industry"

Interview discussion to be conducted by NTNU with relevant companies.
An alternative date can be arranged if required.
Time required 30 min

Initial Contacts are:
The participant is asked to consider all the questions before the interview takes place. The interview call will be conducted with Teams. You are invited to send in notes before or after the interview which assist in answering the questions.

This interview aims to get insights on:

1. Current strategy on sustainability with having the maritime fuel supply in mind
2. The main barriers in the supply chain for compressed hydrogen in the maritime industry
3. Criteria to be fulfilled for considering replacing the current maritime fuel supply with fossil-free fuels
4. The expectations of the supply chain actors

The Questions: Sustainability Strategies/Objectives

- 1) Could you describe the current strategy (overall goals, practices) regarding the future maritime fuel supply for your company?
- 2) Could you elaborate on your company's interest in examining hydrogen as a future maritime fuel?

Main barriers

- 3) What do you see as the main barriers for your company to invest in hydrogen? And why?
- 4) If you shall point out the most critical barrier, which one would it be?
- 5) Could you describe your company's approach to strategy?
  - a) How will you describe the other companies in the supply chain?
  - b) Do you more or less have the same pace or are some investing more ahead than others?
- 6) Does your company worry that the needed technology or infrastructure for zero-emissions fuels is not in place in time? If yes, which one?
- 7) To what extent are you relying on other supply chain actors to take the first steps towards zero-emissions fuels?

Managing the barriers

- 8) Which criteria need to be fulfilled to make you consider investing in hydrogen?

    a) Internal and external, what can they do, what do others have to do?

    b) Explanation of all of them

    c) Are there some barriers that need a joined effort?

    Are some more urgent? The sequence

- 9) How do you see for you that the barriers can be handled?

    a) Are you communicating, on this specific topic?

    b) Have the firms tried to talk to suppliers about investing, how dynamic is the relationship?

    c) Have you fits a similar situation before, and how did you manage it at that time?

- 10) Do you have a plan to begin investing and are you only using fuels from renewable energy sources, and if not, why?

- 11) What are the critical criteria for success within this field?

Others

- 12) Is there anything you think is relevant to this topic, that I did not ask you about?

- 13) Any other comments?

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