The prospect of blue and green hydrogen in Norwegian maritime sector

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The prospect of blue and green hydrogen in Norwegian maritime sector

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This thesis is a part of the master's program in Climate Change Management (Planlegging for klimaendringer) at the Department of Environmental Sciences, Faculty of Engineering and Science at the Western Norway University of Applied Sciences. The author is responsible for the methods used, the results that are presented and the conclusions in the thesis.

Preface

I would like to thank my supervisors, Rune Njøs and Geoffrey Sean Gilpin for their invaluable guidance and feedback which made the completion of this thesis possible. I am also grateful to them for helping me in conducting the Master's thesis in sociotechnical science which have broaden my perspectives and understanding of the dynamics and complexities in dealing with green growth.

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I would like to extend my gratitude to Kimia for her patience throughout the course of the thesis, and Nima and Farzane for their support.

List of abbreviations and acronyms

AE	Alkaline electrolysis
BE	Battery electric
CCS	Carbon capture and storage
EU	European Union
GHG	Greenhouse gas
LNG	Liquefied natural gas
LoZeC	Low- and zero-carbon energy
LPG	Liquefied petroleum gas
MLP	Multi-level perspective
NMSS	Norwegian maritime shipping sector
NPD	Norwegian Petroleum Directorate
NTP	National transport plan
PEM	Proton Exchange Membrane
RE	Renewable energy
SOEC	Solid oxide electrolyser cell
TIS	Technological innovation system

Abstract

In the face of increasing scientific evidence of the threats of anthropogenic climate change, the maritime sector has become more strictly regulated in recent years. To meet the national and international mandatory environmental obligations, low- and zero-carbon energy solutions need to be developed. Interests in hydrogen as an energy career, among different carbon-lean fuels, have increased in Norway's low-carbon energy system due to its ubiquity and versatile applications across sectors. As a leader in green shipping, Norway is well-positioned for implementation of hydrogen in maritime industry in terms of natural resources availability, existing compatible infrastructures and technological expertise for the development of hydrogen. However, application of hydrogen technology in Norwegian maritime sectors is at niche level currently. This thesis provides an overview of the established sociotechnical regime as well as focus on the hydrogen niche and their interactions. More specifically, it focuses on the actors, institutions, and the key drivers and barriers influencing the transition pathways. Transition, in general, do not follow a linear process and may follow different pathways affecting by different actors, networks, and mechanisms. As such, the thesis is assessed the implementation of hydrogen technology in Norwegian maritime sector by employing the multi-level perspective (MLP) and the technological innovation system (TIS) approach in conjunction. Taken together the MLP and TIS in the context, it would be possible to discuss the sociotechnical levels (niches, regimes and landscape), their interaction, and their impacts on hydrogen transition in Norwegian maritime industry. In doing so, the TIS was recruited to inform the MLP about the key factors, particularly factors impacting the blue and green hydrogen transformation processes. The findings and analysis show that the hydrogen transition hinges on the lack of knowledge, regulations, and infrastructure at the entire value

chain. Hydrogen propulsion vessels may sail on a mix of blue and green hydrogen in the foreseeable future, however blue hydrogen might be the dominant type and could be transported via natural gas pipelines at the initial steps. Overall, blue hydrogen should be viewed as a short-term solution to enable a rapid hydrogen transition while green hydrogen would offer better prospects for a more sustainable economy for Norway.

Samandrag på norsk

En økende bevissthet om effekten av menneskeskapte utslipp har ført til at blant annet den maritime næringen opplever strengere reguleringer og krav. For å imøtegå nasjonalt og internasjonalt pålagte miljøkrav er det behov for lav- og nullutslipps energiteknologier som bidrar til dramatisk lavere utslipp av CO2. I tillegg til flere andre lavkarbonteknologier er det økende interesse for hydrogen som energibærer, blant annet i Norge der energisystemet spiller en viktig rolle i å tilrettelegge for hydrogen og de mange anvendelsesområdene til hydrogen på tvers av sektorer og bruksområder. Som et av de ledende landene innenfor grønn skipsfart er Norge godt posisjonert for implementering av hydrogen i maritim næring, noe som blant annet skyldes naturressurstilgang, eksisterende kompatibel infrastruktur og teknologisk ekspertise for utvikling av hydrogen. Implementering av hydrogenteknologi i maritim næring er imidlertid på nisjestadiet. Dette innebærer et behov for oversikt over det etablerte sosioteknologiske regimet så vel så som fokus på ulike hydrogennisjer og samspillet mellom disse nisjene for å forstå omstillingsprosessen. Denne oppgaven fokuserer på aktører, institusjoner og nøkkelbarrierer og -drivere for å projisere mulige «omstillingsretninger» («transition pathways») for hydrogen i maritim næring. Oppgaven bygger på et rammeverk som kombinerer en flernivåforståelse (the Multi-Level Perspective, MLP) og teknologiske innovasjonssystemer (Technological Innovation Systems, TIS). Ved å se MLP og TIS i sammenheng kan man diskutere brede transisjonsprosesser ved å se på sosioteknologiske nivåer (nisjer, regimer og landskap), samspillet mellom disse, samt hvordan dette påvirker implementeringen av hydrogen i den norske maritime næringen. Videre blir TIS anvendt for å informere MLP om nøkkelfaktorer som er sentrale for en oppskalering av nisjene, og empirisk gjøres det en TIS-studie av 'blå' og 'grønne' transformasjonsprosesser knyttet til hydrogen i maritim sektor. Analyse og funn viser at hydrogenomstillingen møter barrierer knyttet til mangel

på kunnskap, reguleringer og infrastruktur gjennom hele verdikjeden. De neste tre tiårene antas det at fartøy med hydrogenfremdrift kommer til å benytte seg av en kombinasjon av grønt og blått hydrogen, men at blått hydrogen kan komme til å dominere innledningsvis ettersom dette kan transporteres gjennom eksisterende gassledninger. Samlet sett bør blått hydrogen ses på som en kortsiktig løsning for å akselerere hydrogenomstillingen, mens grønt hydrogen kan være en bedre løsning på lang sikt for å bidra til en mer bærekraftig norsk økonomi.

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1. Introduction

The growing anthropogenic amount of greenhouse gas (GHG) emissions present challenges for the maritime industry, which is one of the sectors where CO_2 emissions are projected to grow by between 50% and 250% according to the business-as-usual scenario (Smith et al., 2014). As such, the maritime sector has become more strictly regulated in recent years. As the United Nations specialized agency in terms of safety, security, and pollution prevention, the International Maritime Organization (IMO) (IMO, 2021) has adopted mandatory measures to reduce GHG emissions from international shipping by at least 50% compared with the 2008 level by 2050 (Norwegian Government, 2019). In order to meet the international obligations, similar environmental measures were introduced to Norwegian maritime industry. More specifically, Norway defines shipping as a prioritized area for reducing emissions in the recent White Paper on Norway's climate strategy (Ministry of Climate and environment, 2017). In light of that, the Storting[1] has requested the Government to adopt requirements and regulatory measures for cruise ship's pollution and other shipping in tourist destination fjords up to 2030. This includes requirements in the west Norwegian Fjords World Heritage at least by 2026 (Norwegian Government, 2019). Further, the National Transport Plan (NTP) has ambition to use low- and zero-emission carbon (hereafter abbreviated as LoZeC) solutions for vessels in 40% of all short sea shipping (Norwegian Ministry of Transport and Communications, 2016).

Among various type of LoZeC solutions e.g. Liquefied natural gas (LNG), battery electric (BE), biogas etc., hydrogen can be considered as a potential solution for green transition due to the variety of end-users, production methods, and energy sources (Damman, Sandberg, Rosenberg,

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[1] The Norwegian Parliament

Pisciella, & Johansen, 2020). More importantly, due to its lower energy density, hydrogen is a proper alternative for zero-emission shipping on long sailing routes and for energy intensive vessels (Steen et al., 2019). In the context of Norway, green and blue hydrogen are two main thechnologies of producing climate-friendly hydrogen. In these methods, hydrogen can be supplied using fossil fuel combined with carbon capture and storage (CCS; blue hydrogen) or electrolysing water using clean electricity (green hydrogen) as it is elaborated in figure1.

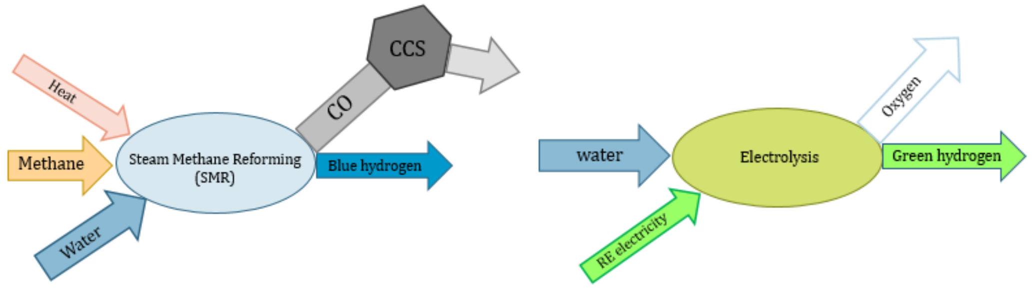

Figure 1. This figure shows two hydrogen production method schematically, green hydrogen on the right side and blue hydrogen on the left side. Green hydrogen is produced via electrolysis and is assumed sustainable provided using renewable electricity as energy source. Currently the majority of blue hydrogen produced globally is based on Steam methane reforming (SMR). The hydrogen produced in this method is considered climate-friendly when it is coupled with carbon capture and storage (CCS) (Statkraft, 2018).

Although Norway has ample access to natural resources and energy for producing blue and green hydrogen i.e. natural gas, water, and cheap renewable electricity (Statkraft, 2018), the Norwegian production of hydrogen for using in maritime sector is at the niche stage and limited to pilot projects at local scales (Steen et al., 2019). Previous studies showed that upscaling with the production and control infrastructures are seen as important for transition to hydrogen maritime technology. More importantly, large-scale development projects would be effective for reducing hydrogen prices by enhancing market formation in maritime sector as well as other cross sectors (e.g. heavy duty vehicles, industry, heating) who are not able to invest on the hydrogen production (Steen et al., 2019). However, there is an uncertainty about the demand, which leads to hesitancy in suppliers, and eventually a complicated "chicken or the egg" dilemma (Damman et al., 2020).

Thus, dealing with the challenges of transition to hydrogen maritime technologies cannot be accomplished only by relying on technological innovation (Steen et al., 2019) since the shipping industry, as a sociotechnical system, is a configuration of interrelated elements comprising people, tasks, organizational structures, and technologies (Leavitt 1965; Praetorius 2014; de Vries 2015).

Against this background, the main objective of this thesis is formulated to provide an understanding of the current sociotechnical challenges of transformational changes in Norwegian maritime shipping sector (hereafter NMSS) to replace the marine diesel with hydrogen as a LoZeC alternative. Further, it aims to specifically analyse the potential transition pathways of green and blue hydrogen in NMSS. Hence, the objective of the thesis is to address the following research questions:

RQ 1: What is the prospect of regime change towards hydrogen technologies in the Norwegian maritime industry?

RQ 2: What are the potential transitions pathways based on upscaling of the blue and/or green hydrogen niches?

Scholars generally have approached the analysis of such a radical innovation transformation from at least two different point of view. Either they focus on investigating broader transition processes, or studying the dynamics of a particular innovation by addressing the most important drivers and barriers for a successful diffusion of a particular technology or product (Markard & Truffer, 2008). This thesis has employed the multi-level perspective (MLP) and the functions of technological innovation systems (TIS) approach. The MLP is adopted to address the first research question which is concerned about the transition at a more aggregated level. MLP is a useful tool for analyzing how major shifts in sociotechnical transitions can occur through interaction of developments at three levels: sociotechnical landscape, sociotechnical regime, and technological niches (Geels, Green, & Elzen, 2004). To answer the second research question, a TIS approach is recruited which would be useful for understanding the innovation value chain, actors, networks, and institutions as well as the drivers and barriers for the transition to blue and green hydrogen in NMSS. Then, the eventual pathway of green and blue hydrogen transition in NMSS is assessed by discussing MLP and TIS in conjunction.

To deal with the uncertainties and addressing the above-mentioned questions, in the next section a description of the theories used for the analysis i.e. MLP and TIS frameworks is presented. The third section lays out the research design and methodology of the thesis, and presents information about the case studies. The forth section presents the results and discussions and is divided into two sub-sections. The first sub-section corresponds to the MLP framework, which analyses the main sociotechnical characteristics of the NMSS i.e. the regime, the landscape, and hydrogen as nice-innovation. This is followed by sub-section 4.2. which provides a TIS assessment of blue and green hydrogen niches in NMSS. The fifth section discuss the challenges of upscaling two sub-niches, how the changes interact with the broader landscape. Finally, a brief summary and areas for future research are outlined in the last section.

2. Theory

Technology has an essential role in fulfilling societal functions, however artefacts themselves have no power individually, and just in collaboration with human agency and social structures and organizations can fulfill functions (Geels, Green, & Elzen, 2004). In real life situations we always run into artefacts in the context, hence assessing the artefacts in a framework combining the social and technical elements provides an appropriate unit of analysis (Fleck, 2000).

Sectors like maritime transportation consists of different elements i.e. networks of actors, infrastructures, material artifacts and knowledge, thusly it can be conceptualized as a sociotechnical system (Frank W. Geels, 2004). Sociotechnical systems were defined to include all the factors related to an artefact influencing a cluster of elements comprising technology, regulation, user practices and markets, cultural meaning, infrastructure, maintenance networks, and supply networks (Geels, Green, & Elzen, 2004). More importantly, the tight interlink and dependence of the system's elements on each other has crucial implications for the dynamics the systems exhibit as well as the system transformation (Markard, Raven, & Truffer, 2012).

In this conceptualization, a major transformation in the system or 'transition' can be realized by configuration from one sociotechnical system to another including technological substitution, and far-reaching changes in elements such as user practices, regulations, infrastructures, etc. (Geels, Green, & Elzen, 2004). However, niche technologies often hardly can break through, and have a mismatch with the established sociotechnical system (Frank W. Geels, 2002). Various strands of research have been developed for the study of sociotechnical transition process, however the multi-level perspective framework (MLP) and the technological innovation system (TIS), are of the central strands (Markard et al., 2012).

The TIS approach has attracted attentions for evaluating radical innovations with a potential to challenge the existing sociotechnical system. It has obtained a high degree of validity for policymaking, however it could not identify the transformation's features. However, the TIS perspective might be assumed as inward oriented due to less attention to the system's environment. The MLP framework has focused on the latter, however it is less satisfying in formulating clear justifications for policymaking. It is argued here that a combination of the two approaches can cover the weaknesses and improve the strengths. TIS approach provides an analytical basis using its elaborated framework of functional assessment which could be applied as a complementary method for MLP particularly for understanding niches (Markard et al., 2012).

Accordingly, the next sub-section introduces the MLP framework which was recruited to answer of the first research question. This framework was applied for understanding the prospect of the regime transformation towards a green shipping, and the potential transition pathways. This follows in the sub-section 2.2. which explains the TIS as the selected method for studying the challenges of upscaling with green and blue hydrogen sub-niches. This approach was conducted to build a bridge the MLP and TIS.

2.1. The multi-level perspective framework (MLP)

The MLP framework is a useful exploratory tool for assessing and understanding how major shifts in technology can happen through interaction of three distinguishable levels i.e. sociotechnical regimes, sociotechnical landscape, and technological niches (Geels, Green, & Elzen, 2004). A sociotechnical regime proposes the rule-set carried by different social groups (see figure2) including users, policy makers, societal groups, suppliers, scientists, capital banks, etc. (Frank W. Geels, 2002). Since activities of these groups are guided by semi-coherent set of rules, these social groups go to aligned trajectories on similar directions, and create stability and resilience. This stability and resilience means that in sociotechnical regime the innovation leads to incremental changes to the current system (Frank W. Geels, 2002).

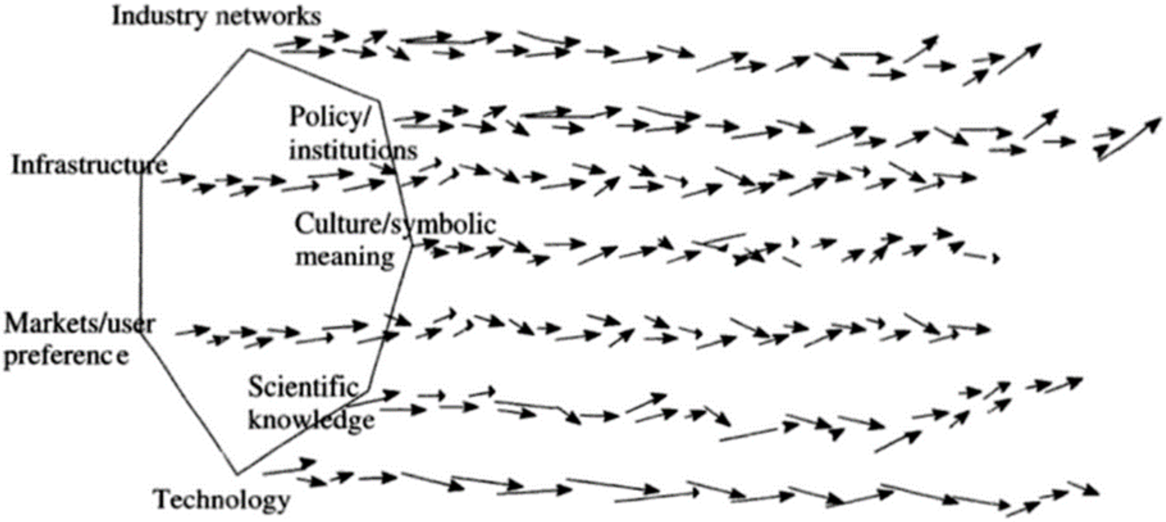

Figure 2 Trajectories of socio-technical regimes (Geels, Green, & Elzen, 2004).

The sociotechnical landscape mainly refers to aspects of the wider external system which impacts sociotechnical development e.g. cultural changes, environmental problems and globalization. Landscapes are beyond the direct influence of actors and cannot be changed by their will. It entails a set of heterogeneous, slow-changing factors (e.g. cultural and normative values, environmental problems) and shocks and surprises (e.g. wars, recessions) (Geels, Green, & Elzen, 2004).

The niche level provides a space for learning processes and building a supportive social networks for niche technologies which are often cumbersome, expensive, and have relatively low technical performance. This level has loose and vague structuration which allow the niche-actors to do experimentations and activities in various directions with a weak coordination (Geels, Green, & Elzen, 2004). Sociotechnical transformations for niche technologies that have fundamental differences with prevailing regime is not easy due to the existing regime’s resistance. Therefore, dedicated actors incubate niches in order to preventing their breakthrough (Geels, Green, & Elzen, 2004). Typically, the radical potential of novelties is not visible at the beginning and niches often used for solving challenges in the existing regime. Hence, radical innovations may step by step stabilize in the existing regime but can break through from the niche-level and speed up the changes when landscape developments open a window of opportunity (F. W. Geels, 2005).

At the initial phase of transition, at niche level there is not yet a dominant design for novelties which may result in competition among various technical forms. However, niche-innovations may build up internal momentum through learning-by-doing process, price and performance improvements, and support from powerful groups. On the other hand, landscape changes create pressure on the regime and destabilize it. Then, destabilization of the regime may lead to emergence of windows of opportunity for novelty. The alignments of these processes gradually leads to emergence of niche networks, stabilization of its rules, development a dominant technical design for novelty, articulation of user preferences, and eventually the breakthrough of novelty in mainstream markets where it competes with the existing regime. Figure 3 elaborates a somewhat standardized picture of this dynamic (Frank W. Geels & Schot, 2007). However, scholars found four different patterns for a niche-innovation upscaling which are referred to ‘Transition pathways’.

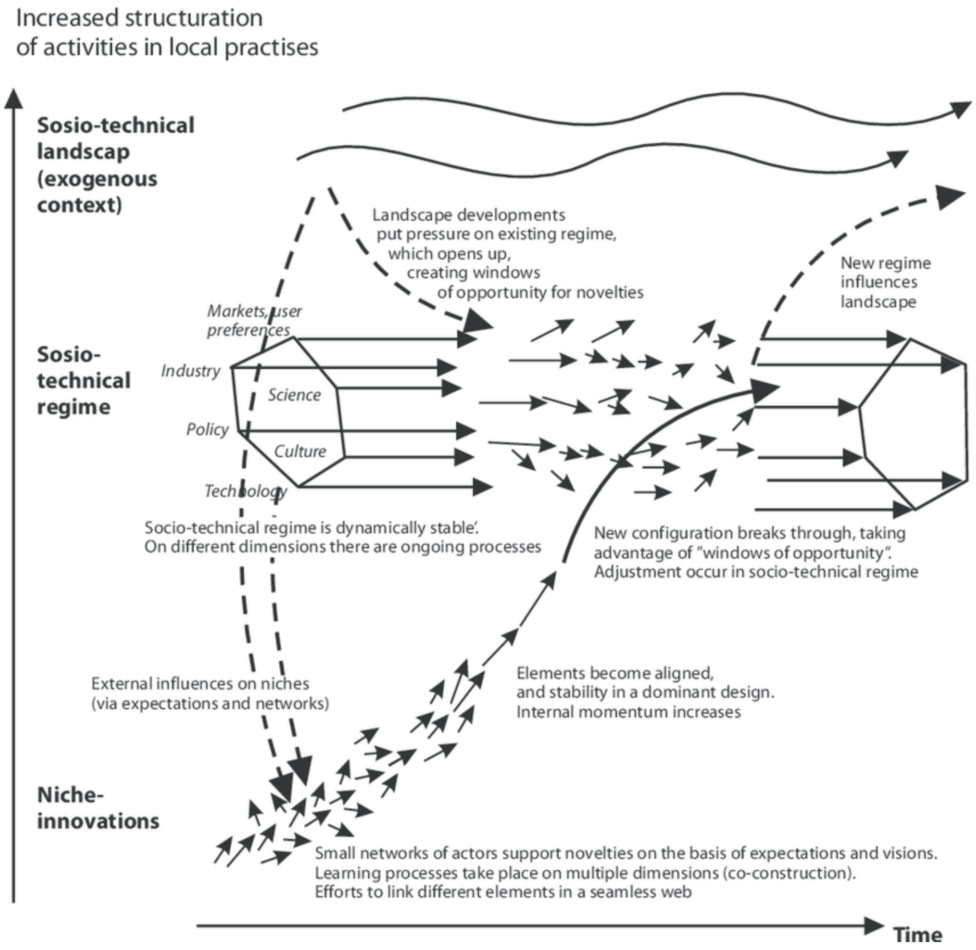

Figure 3 A dynamic multi-level perspective on system innovation(Frank W. Geels & Schot, 2007).

2.1.1. Transition pathways

Under the MLP, there are four main types of transition pathways i.e. substitution, transformation, reconfiguration, or de-alignment and re-alignment (see table1). Each pathway can appear from the different ways the regime interplay with the niche and landscape. The regime interaction with niche and landscape is based on the preparation of niche-technology for the window of opportunity as well as the type of the interrelation between technology and existing regime which could be competitive or symbiotic (Geels & Schot, 2007).

Table 1. Transition pathways and their differences. Based on (Frank W. Geels & Schot, 2007).

Pathways	Main actors	Interactions
Technological substitution	Niche actors New core actors emerge	Niche innovation replace the existing regime-bottom-up push
Reconfiguration	Integration of new core actors	Niche innovations adopted into existing regime and change system architecture
Transformation	Incumbent actors	Incumbent actors change regime elements accommodate external pressure
De-alignment and Re-alignment	Landscape actors	Landscape change led to regime breakdown + niches gradually align around winner

The substitution pathway typically occurs when niche-innovations have achieved to a sufficient maturity for competing with the existing regime in case of window of opportunity. It can also happen if the niche-technology had developed outside of the regime by either earlier entrants who compete for the established incumbent firms, or outsider like activists, social movements actors, citizens or incumbents from other sectors. Figure 4 illustrates the situation that window of opportunity is triggered by a ‘specific shock’, ‘avalanche change’ or ‘disruptive change’ in the landscape applying pressure on the regime and creating major regime tensions (Geels & Schot, 2007).

A ‘specific shock’ is defined as a rapid and intensive change that occurs rarely and in a quite limited range. The specific shock may dissipate and disappear after a while and return to the base line, however has the capacity to generate quick and significant changes in a few environmental dimensions (Frank W. Geels & Schot, 2007). Whereas ‘disruptive change’ corresponds to infrequent changes that emerges small and moderate initially but progressively escalates to have a considerable influence on one environment dimension. ‘avalanche change’ occurs rarely, but quickly and in high intension which simultaneously impacts multiple dimensions (Geels & Schot, 2007).

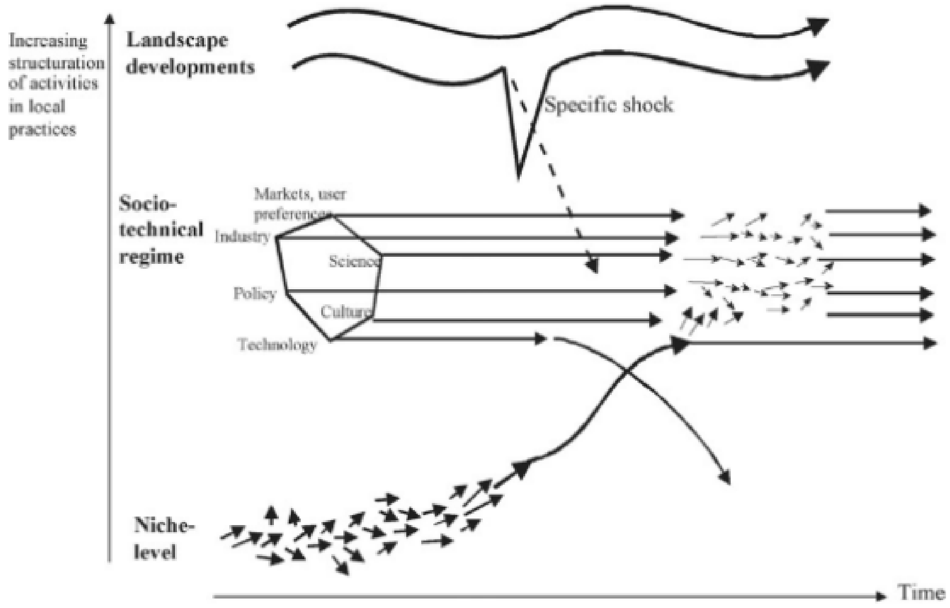

Figure 4. Substitution pathway of transition in the MLP framework (Geels & Schot, 2007).

In the transformation pathway, the niche innovation is not completely established when modest changes in the landscape or disruptive changes apply pressure on the regime. As such, it leads to only incremental adjustments of the regimes rules by incumbent actors (Frank W. Geels & Schot, 2007). The speed and degree of the regime reorientation depends on the socio-political power pressure and how the market opportunities are grasped (Frank W. Geels et al., 2016). Figure 5 illustrates the dynamics of the transformation pathway.

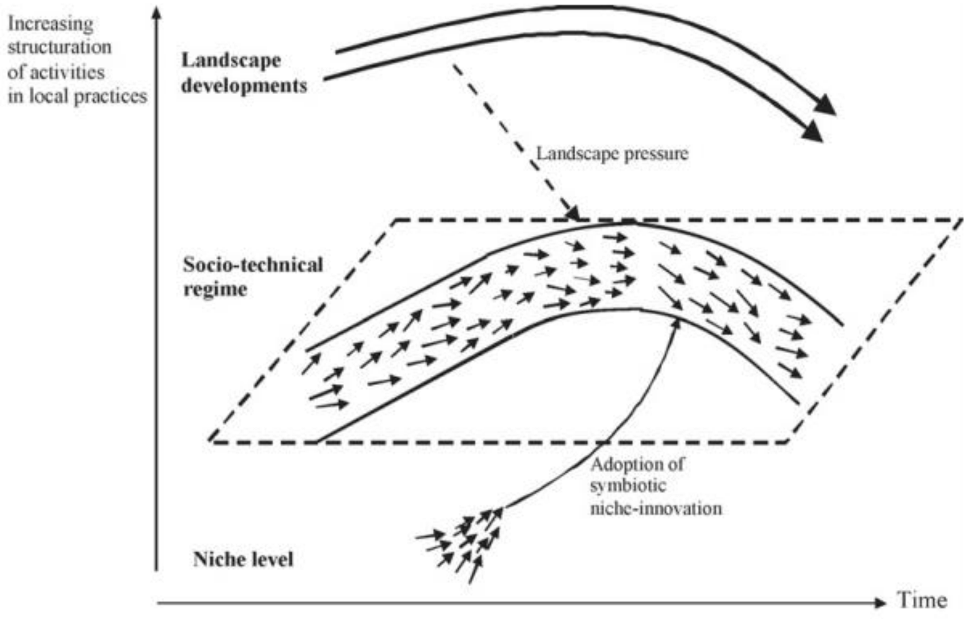

Figure 5. Transformation pathway (Frank W. Geels & Schot, 2007).

The reconfiguration pathway entails new alliances that are set up between symbiotic niche-innovations and the existing regime (Frank W. Geels et al., 2016). Its initial phase is the same as the transformation pathway whereby symbiotic innovations which are developed in niches, are originally adopted in the regime to solve minor problems. If the basic architecture of the regime remains the same it would be a transformation pathway. However, the adopted niches may cause further adjustments as regime actors encounter new problems and/or identify new opportunities to explore new combinations between old and new elements and learn more about niches. Therefore, this may cause changes in system components and relations such as technical changes, changes in user practices, perceptions and search heuristics. As such it will lead to a major configuration on regime's basic architecture as Figure 6 illustrates.

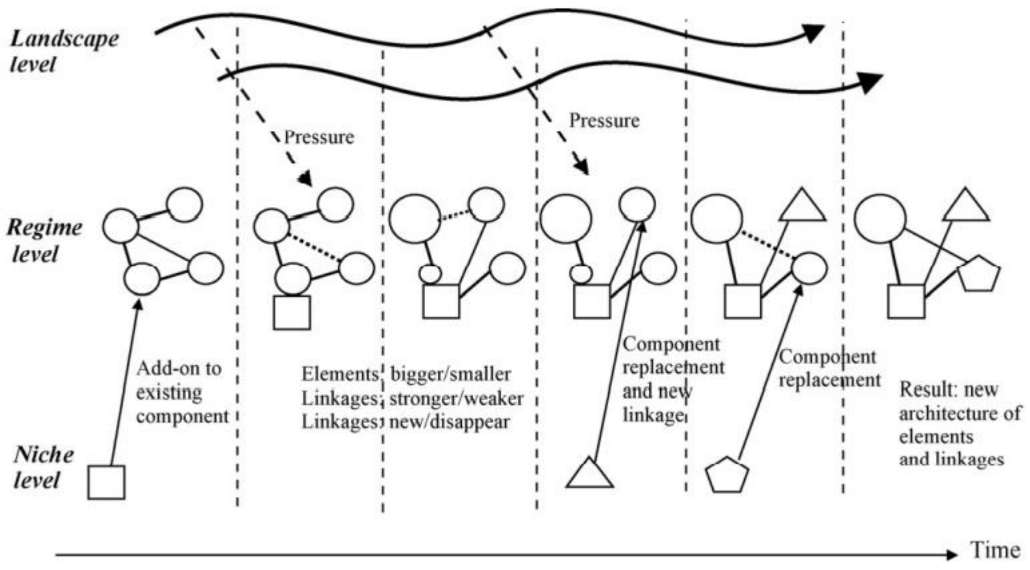

Figure 6. Reconfiguration pathway (Frank W. Geels & Schot, 2007).

This pathway occurs when one niche-innovation gains momentum and becomes prevalent as it shows in figure 7. The existing regime will re-align itself and become re-established as a new regime when landscape pressure in the form of disruptive change initiates the transition with transformation, then leads to reconfiguration and eventually follows by substitution or de-alignment and re-alignment (Frank W. Geels & Schot, 2007).

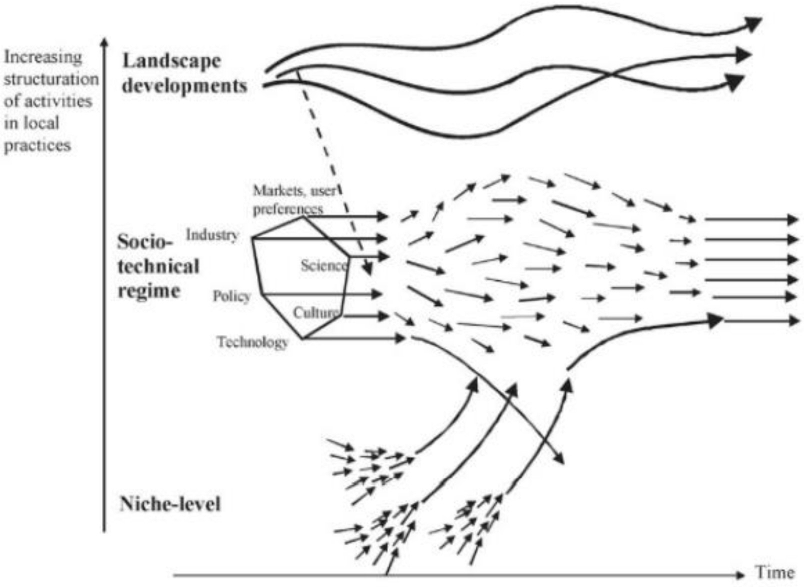

Figure 7. De-alignment and Re-alignment pathway (Markard & Truffer, 2008).

In summary, the MLP approach evaluates innovation and transition processes by the interaction of stabilizing functions at the regime level and destabilizing landscape pressure in combination with the exposure of niche innovations (Geels, Green, & Elzen, 2004). To gain in-depth understanding of the hydrogen as a niche technology in this thesis, a TIS analysis was conducted to build a bridge between transition MLP and the an in-depth understanding of niches.

2.2. Technological innovation system (TIS)

The TIS is one of the major lines of inquiry in the innovation system and in the field of sustainability transitions where it is most often applied to analyze the early development phases of, for example, new renewable energy technologies (Markard et al., 2012). The TIS concept is concerned with the emergence of niche technologies and the institutional and organizational changes that associate with technology development. The TIS approach highlights inter-organization interlinkages comprising public and private sectors, nurturing and distribution of knowledge, and establishment of infrastructures and institutions. As such, a TIS assessment starts with mapping the elements including actors, networks and institutions associated with the studied TIS. Every TIS basically comprises the same actors, as is shown in figure 8, namely higher education institutes, public research organizations, government agencies and policies, financial organizations, industry, support organizations (mainly network-enabling and political lobbying); and institutions (Botta, McCormick, & Eis, 2015).

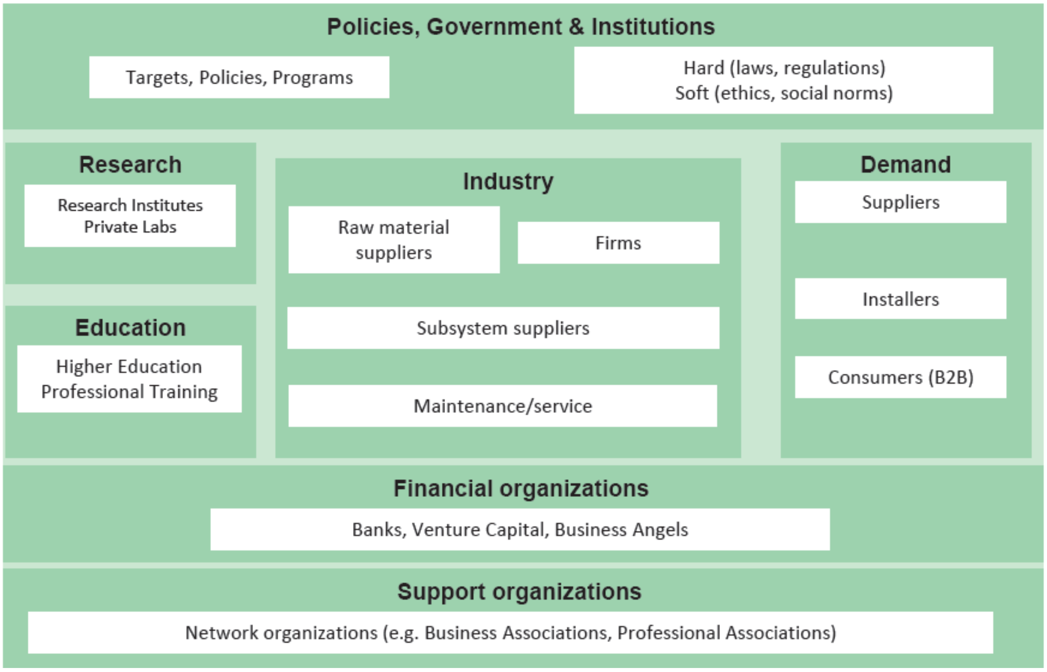

Figure 8- Structure of an innovation system based on Hekkert (Botta et al., 2015).

Challenges in technology development and diffusion can be recognized by analyzing essential emerging mechanisms in the TIS. Dynamics of a number of essential processes, labeled ‘functions’, influence the performance of the innovation system by affecting on the development, diffusion and use of technology. By evaluating the performance of an innovation system scholars identify and analyze the functions that are performed in the TIS. (Binz & Truffer, 2017). Knowing that functions influence each other and the innovation system positively and negatively, it can be considered that any systemic problem has root in the system’s functions. Table 2 shows the list and description of the seven essential system functions including: knowledge production and diffusion, entrepreneurial experimentation, resource mobilization, guidance of the search, market formation, creation of legitimacy, and the creation of positive externalities (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008).

Table 2. TIS functions based on (Bergek et al., 2008).

Functions	Description
Knowledge development and diffusion	Development and diffusion of the knowledge of the core of a TIS, sharing of knowledge between actors within the system and new combinations of knowledge as a result of these processes.
Entrepreneurial experimentation	Testing various applications and solutions as the experimentation leads to problem-solving and uncertainty reduction at different scales.
Market formation	Providing a basis where goods and services can be exchanged in semi-structured ways between suppliers and buyers which is resulted in articulation of demand and preferences, product positioning, standard setting, and development of rules of exchange.
Direction of search	Mechanisms that indicates the routs that firms and other actors apply their resources, incentivizing and pressuring them to engage in innovative work within a TIS and determining what strategic choices they make within that field.
Resource mobilization	Allocation of different types of resources for the development, distribution and implementation of new technologies, products and processes, most notably financial, human capital resources and complementary assets (e.g. infrastructure).
Legitimation	The process of formation of regulative, normative and cognitive legitimacy within the TIS and its proponents in the eyes of relevant stakeholders (i.e. increasingly being perceived as complying with rules and regulations, societal norms and values, and cognitive frames).

Development of positive externalities	The creation of system-level benefits for all actors within the TIS as a result of an investment or action made by another actor, such as pooled labor markets, complementary technologies and specialized suppliers.

Functions’ interaction and momentum influence each other and the overall performance of the system positively or negatively, and can lead to structural change in system. Although many different interactions are possible, the number of possible starting points are limited. Figure 9 depicts three initial patterns or motors of change that the development often starts there. The direction of search function is typically a possible start point when societal problems are identified and governmental goals are set to reduce the environmental damage. These goals promote new resources which lead to knowledge development and diffusion about the new technological option.

The other possible motor of change starts working from entrepreneurial experimentation and may legitimize the new technology, can provide more resources to perform R&D, cause market formation. By emergence of market, a boost in entrepreneurial activities leads to knowledge development and diffusion (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007).

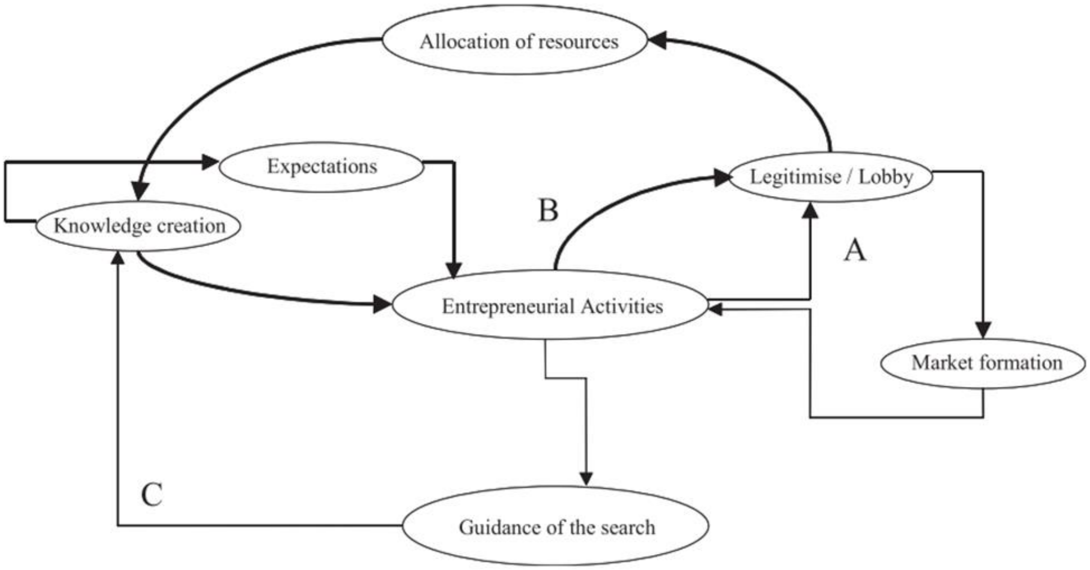

Figure 9. Typical motors of change (Hekkert et al., 2007).

In sum, TIS and MLP are two common concepts for the study of transformational changes as well as analysis of niches. Although, these methods are closely related and draw on common theoretical roots, they have some differences. This thesis is adopted both of them in combination in order to combines the strengths of the two approaches and allows providing a better understanding of the eventual regime change in NMSS towards a green shipping.

3. Research design and methodology

As it is mentioned earlier, dealing with the immense challenges of transition to hydrogen maritime technologies cannot be accomplished only by relying on technological innovation since the NMSS as a sociotechnical system is influenced by a configuration of elements like policy, markets, consumer practices, technology, etc. Thus, this thesis takes a sociotechnical approach to look beyond single dimensions without losing the complexity of the system. As such, I conducted a qualitative approach to address the research questions and build on a thorough perception of the hydrogen transition in NMSS. A qualitative research focuses in understanding a research question using empirical and non-numerical data and can shed light on the unapparent societal dimensions of transition. Knowing that a complete analysis of the NMSS regime and hydrogen niche is very challenging, hence three case study projects were selected among projects within the maritime hydrogen value chain in Western Norway.

3.1. Case study selection

To obtain a general overview of the existing projects and their purposes, an online investigation was conducted on projects which their actors' have intentions to contribute in hydrogen production in Norway. To this end, press release and the major firms' webpages i.e. the Ocean Highway Cluster, Equinor, Research Council of Norway, Statkraft, etc. were investigated. Subsequently, a list of relevant projects was provided in apendix1. In order to attain credibility, the projects were checked with the list of the hydrogen production sites published in the HyInfra project's report '*B1.2: Future compressed hydrogen infrastructure for the domestic maritime sector (IFE)*'. This project leads by Arena Ocean Hyway Cluster, and the mapping of future hydrogen (Danebergs & Aarskog, 2020). As it was impractical to attempt to study all the projects in the list to address the research questions, studies were conducted on the selected projects which are demonstrating the maritime hydrogen value chain in Western Norway. Furthermore, considering that the majority of the projects were planned to produce green hydrogen, it was decided that one blue and two green hydrogen project, namely 'CCB Energy Park', 'Hyfuel' and 'Hellesylt Hydrogen Hub', could provide the best sample. More importantly, all the projects are planned to contribute into large scale hydrogen production and tap into the maritime sector market. Further, the projects involve firms from the different part of the hydrogen value chain which provide the opportunity for further data gathering.

In Kollsnes, Øygaarden, the companies CCB and ZEG Power have received funding to establish capacity for hydrogen production based on natural gas as feedstock at CCB Energy Park. Utilizing ZEG Powers' enhanced reforming technology, Sorption Enhanced Reforming (SER) with integrated Carbon capture makes it a clean hydrogen production method from methane (zegpower, 2021). The Hellesylt Hydrogen Hub, a consortium of major actors in hydrogen field comprising

Hexagon, Hyon, TAFJORD, Fiskerstrand, Gexcon, SINTEF, and the local municipality of Stranda; joined forces to achieve zero-emission operations in the Geirangerfjord, one of two World Heritage Fjords in Norway. The project has started in January 2020 and it is predicted to deliver green hydrogen latest by 2023. This project could reduce the CO_2 emissions in the Geirangerfjord with 2,370 tons per year (HYON, 2021). The Hyfuel company was founded by INC Gruppen and Sogn og Fjordane Energi (SFE) and they have brought with them partners including Gasnor, Ocean Hyway Cluster, and Høgskulen på Vestlandet (HVL). The project has located in the coastal town of Florø in Western Norway, and Innovation Norway has granted the pilot project. The company will develop with the aim of establishing a plant for hydrogen production at Fjord Base, and supply hydrogen and LOHC to the maritime industry, as well as utilizing the by-products of electrolyzing i.e. oxygen and heat in other sectors (Hyfuel, 2021).

3.2. Data collection

Qualitative data in this study was mainly gathered based on semi-structured interviews which formed the core of my empirical data. Moreover, secondary data from reports, governmental documents, etc. were the other main data sources of this thesis. In total, seven semi-structured interviews in April 2021 held mainly with senior-level managers in companies and organizations involved in the selected hydrogen development projects from different part of the value chain. Interviews were conducted via Zoom due to COVID-19 pandemic limitations, and each interview session lasted in a range between 40 min to 1 hr.

3.2.1. The semi-structured interview

Semi-structured interviews refer to the main data gathering method for this thesis which allows me to have guidance and flexibility while asking a set of fixed questions. Semi-structured interview can create a conventional channel of information gathering by providing space for spontaneous answers (Harrell, Margaret & Bradley, Melissa, 2009). One of the main advantages of this technique is the flexibility in choosing different vocabulary in the method which yields benefit for interviewing a group of people whom English is not their native language, and verifies that through careful choosing the words, valid and reliable information could be attained (Barribal & While, 1994). Clearly, in this type of interview, validity and reliability rely on conveying equivalence of meaning which standardize the interview and enable comparability. Considering that the wording and sequence of all the questions in the interview guideline are similar for respondents so any differences in the answers supposed to be due to variety in respondents' point of view rather than in the questions asked (Barribal & While, 1994).

In light of that I adopt the semi-structured interviews in order to obtain more in-depth understanding of specific TIS functions, the MLP's levels as well as studying actors, networks, and institutions shaping the development projects. Appendix B shows the complete list of questions as presented to interviewees, which were formulated based on the literature reviews.

The questions in the interview guideline were formulated single-faceted (Cridland, Jones, Caputi, & Magee, 2015) and open-ended in a sense to achieve the richest possible data (Turner, 2010). In this interview guideline questions generally starts with words including *what, how, where, why,* or *when* to encourage the interviewees to answer the questions in a descriptive way (Chenail, 2011). More specifically, the interview guideline consists of two levels of questions. First, the main themes which are covered the main content of research subject and would usually be asked of all the participants (Astedt-Kurki & Heikkinen, 1994). Second, the follow-up questions are used to make the main themes more understandable for the interviewees (Turner, 2010). For this purpose, the pre-designed follow-up questions was used due to increas the consistency in the interviews (Krauss et al., 2009).

3.2.2. literature review

An essential phase of the semi-structured interview development is using previous knowledge to gain a comprehensive and adequate understanding of the topic (Kallio, Pietilä, Johnson, & Kangasniemi, 2016) to contextualize the questions, and formulating the contents and structure of the interview schedule (Rubin & Rubin, 2005). An integrative review was done on literature from various sources comprising peer-reviewed scientific papers, hydrogen and innovation related reports, reports from research institutes such as SINTEF, and reports from energy consultancy agencies like DNV GL. Literature related to Norwegian hydrogen technology prospects and its importance to Norway were based on reports found on government websites, particularly Government.no, Energy Facts Norway, and Statistics Norway.

3.3. Data Analysis

Analysis of the interview data was begun with a set of transcripts of the conducted interviews. To this end, I provided a complete, written copy of the recorded interview, then tried to identify codes by reading through transcripts. Codes are a shorthand representation of some set of issues and ideas that might be identified during the literature review or during reading through the transcribes. This process in some cases followed by another data gathering process regarding the topics that interviewees mentioned in the interviews.

3.4. Limitation of scope

Due to COVID-19 pandemic situation, all the interviews were conducted virtually via video conference applications i.e. Zoom and Microsoft Teams. Further, due to the lacks of proficiency in the Norwegian language, most of the literature reviewed in English. Also, the Google Translation tool was used for studying the important reports which were only available in Norwegian, such as the DNV reports.

4. Findings and analysis

To understand the prospect of the transformational changes in the NMSS's current regime and transition to hydrogen, the MLP approach was adopted based on the data gathered using literature review and interviews. To this end, three distinguishable levels (i.e. sociotechnical regimes, sociotechnical landscape, and technological niches) and their interactions were identified. In light of that, the next sub-sections explain the existing sociotechnical regime in NMSS, the landscape changes, and the hydrogen maritime technology as the niche innovation.

4.1. The MLP analysis

4.1.1. The socio-technical regime

In the context of Norway, the sociotechnical regime refers to the maritime energy regime which functions under a system of semi-coherent practices and rules that is mainly shaped by public regulators like Norwegian Maritime Authority[2], Norwegian Public Roads Administration[3], and private classification companies like DNV.

The Norwegian maritime industry is the second largest export industry after oil and gas, and Norway was the world's seventh largest shipping nation measured by number of vessels in 2018 (Norwegian Government, 2019). The Norwegian maritime industry is one of the strongest and most dynamic industries, including shipping companies, maritime services, shipyards and equipment suppliers. The maritime industry has great importance, particularly in rural parts of Norway and much of the long-distance transport of cargo is transported by ship along the coast.

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[2] *Sjøfartsdirektoratet*

[3] *Statens vegvesen*

Moreover, many communities along the Norwegian coast are connected by fast-going passenger boats with capacities ranging from 10 to more than 100 (Norwegian Government, 2019).

The NMSS is a mature, multi-segmented and highly heterogeneous sector that includes vessels ranging from massive intercontinental freight and bulk carriers to small passenger vessels. There are different categories of vessels in this sector based on fleet structure and operating patterns including scheduled passenger vessels and ferries, cruise ships and international passenger ferries, cargo vessels, offshore support vessels, specialized vessels including aquaculture service vessels, fishing vessels and recreational craft (DNV GL, 2015).

After the Norwegian Maritime Authority, Norwegian Public Roads Administration (hereafter Statens vegvesen) and local authorities are the other key actors who play role in this regime as public procurers and regulators. They do not own vessels but responsible for providing transport in certain routes. Particularly, they are key actors for development of climate-friendly solution, due to their role in stating demands regarding emissions and the technology should be used for the ships operating (Steen et al., 2019). Changes in public procurement of passenger and road ferry services was seen as of central mechanisms for stimulating the technological shift to hydrogen in NMSS: *'Many people think that regulation and economic instruments are important but the really strong tool is that the regulation says for this ferries and for shipping within this line we need hydrogen, this sort of regulations are the strongest, much stronger than the economic tools'* (Informant 7). Over the past decades, Staten vegvesen have developed public tenders and contracts to combine commercial competition with new technology development and system demonstrations. The improving impact of public procurement contracts is also documented in other LoZeC solutions such as biogas and BE (Steen et al., 2019). Regarding the hydrogen-powered ferries, public procurement contracts, in particular Staten vegvesen's new road ferry contract direct attention to both blue and green hydrogen.

DNV (former DNV GL[4]) is a key classification and consultancy company for the maritime industry which is also contributing in certification and technical advisory services to the energy value chain including comprising renewables, oil and gas, and energy management (DNV, 2021). More importantly, the DNV is known as the most influential Norwegian actor in alternative solutions, namely BE and hydrogen. It appears to be among the most central actors in the EU green shipping knowledge network (Steen et al., 2019).

The DNV Gl distinguished 273 different vessel segments based on the type of ship, ship size, and time spent in domestic waters. Moreover, they have different types of owners and customers, and they belong to different sectors and value chains (DNV GL, 2015). Freight ships, fishing vessels, passenger vessels, and offshore supply vessels are the dominant types of vessel that operate in domestic and near-shore or coastal area (DNV GL, 2015). At present, there are around 140 ferry services in Norway including 17 services as a part of the national road system, and in sum, 203 passenger and car ferries are in operation in Norway. As shown in table 3, the average age of the vessels in the ferries and high-speed vessel category is 26 years. Many of the ships that are built in the next few years will probably work at least for 20-25 years (Norwegian Government, 2019). Thus, postponing the promotion of a transition strategy to green shipping may result in a path dependency in fossil fuels in NMSS.

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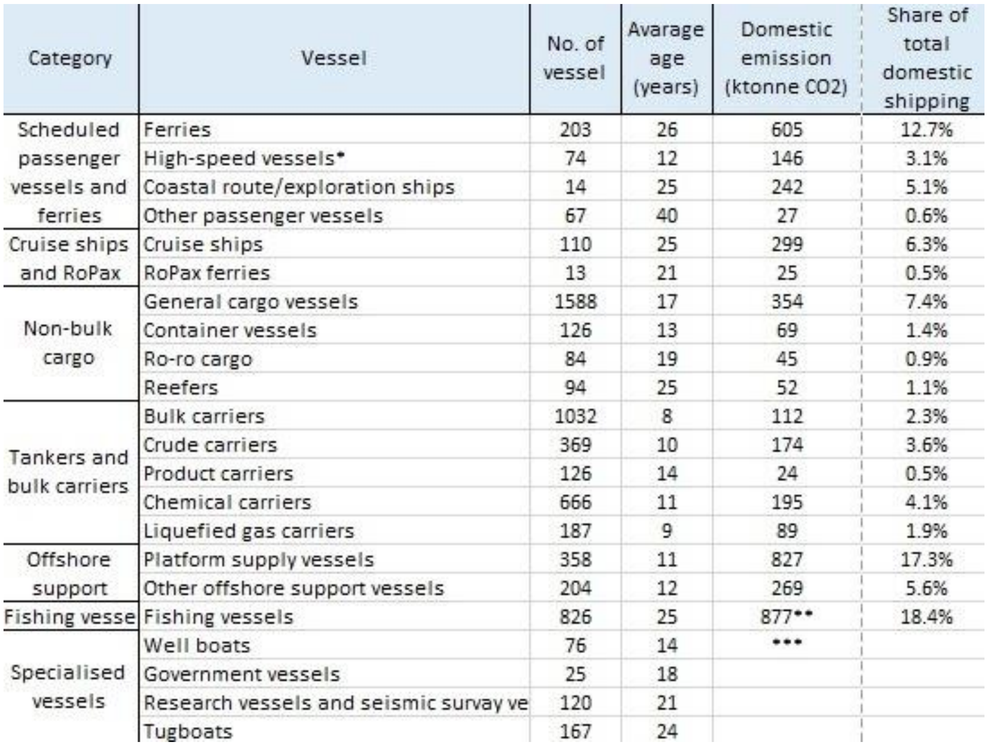
[4] From 1 March 2021 DNV GL become DNV (DNV, 2021).

Table 3- There are different categories for vessels based on their type, size and application. Fishing and shipping accounts for 19% of transport emission in 2017, of which 90% was from shipping (Norwegian Government, 2019).



Category	Vessel	No. of vessel	Avarage age (years)	Domestic emission (ktonne CO2)	Share of total domestic shipping
Scheduled passenger vessels and ferries	Ferries	203	26	605	12.7%
	High-speed vessels*	74	12	146	3.1%
	Coastal route/exploration ships	14	25	242	5.1%
	Other passenger vessels	67	40	27	0.6%
Cruise ships and RoPax	Cruise ships	110	25	299	6.3%
	RoPax ferries	13	21	25	0.5%
Non-bulk cargo	General cargo vessels	1588	17	354	7.4%
	Container vessels	126	13	69	1.4%
	Ro-ro cargo	84	19	45	0.9%
	Reefers	94	25	52	1.1%
Tankers and bulk carriers	Bulk carriers	1032	8	112	2.3%
	Crude carriers	369	10	174	3.6%
	Product carriers	126	14	24	0.5%
	Chemical carriers	666	11	195	4.1%
	Liquefied gas carriers	187	9	89	1.9%
Offshore support	Platform supply vessels	358	11	827	17.3%
	Other offshore support vessels	204	12	269	5.6%
Fishing vesse	Fishing vessels	826	25	877**	18.4%
Specialised vessels	Well boats	76	14	***	
	Government vessels	25	18		
	Research vessels and seismic survay ve	120	21		
	Tugboats	167	24		

* In addition, there are approximately 130 scheduled high-speed vessels below the minimum size of the mandatory AIS report in Norway.

** There are additional emissions from small fishing boats that are not included in the estimate from the AIS system.

*** Total emissions from this category are estimated to correspond to about 7% of emissions from domestic shipping and fishing vessels. Figures are not available for sub-categories.

The international maritime organization (IMO) is the other key actor who influence the shipping industry by shaping the rules and obligation in the global scale as the United Nations' specialized agency. The IMO's objective is to develop and maintain a precise regulatory framework for the safety and security of shipping and the prevention of pollution by shipping industry (IMO, 2021).

The NMSS has been subjected to various international and national regulations during time. The International Convention for the Prevention of Pollution from Ships (MAPROL) has been implemented in Norwegian law. This regulation covers pollutants such as oil pollution, noxious liquid substances in bulk, air pollution, etc.(Norwegian Maritime Authority, 2017). Furthermore, IMO has adopted mandatory measures in April 2018 to reduce emissions of greenhouse gases from international shipping (Smith et al., 2014). Norway chaired the negotiations that resulting in the introduction of stringent environmental obligations for international shipping by the IMO. Considering that maritime industry is the second largest Norwegian export industry (Norwegian Government, 2019), Norway has great ambition to promote the adoption of Norwegian innovation in the development of international framework by maintaining its leading position (Norwegian Government, 2019). As such, having a larger fleet sailing under the Norwegian flag plays important role. To this aim, Norway promotes environmental measures not only for the existing fleet under Norwegian flag also encourage ship-owners to register lean-carbon ships in the Norwegian registers by giving incentives (Norwegian Government, 2019). Incentivizing the LoZeC ships will strengthen the LoZeC niches, especially the hydrogen niche due to its suitability for energy intensive vessels (Steen et al., 2019).

Many interviewees indicated that the political will would be the greatest driver for development of hydrogen technology in NMSS currently: '*The spreadsheet cannot change the world, but the politicians can'* (Informant 5). The Government has great ambition to reduce the emission of domestic shipping and fisheries by half by 2030 and promote the implementation of LoZeC solutions for all vessel categories. To this end, '*The Government's action plan for green shipping*' was presented in order to cutting domestic GHG emissions, strengthening the Norwegian shipping industry and participating in the global required technological developments to meet the Paris Agreement objectives (Norwegian Government, 2019).

Norway has introduced several excises to the shipping industry. CO2 tax on mineral oil introduced in 1991 is one of the most important instruments due to the reduction of CO2 emissions (regjeringen, 2020). The standard carbon tax rate applies to shipping, including LNG and liquefied petroleum gas (LPG) for domestic shipping (Norwegian Government, 2019).

Against these changes, the maritime industry has increasingly re-adjusted itself. Norwegian ship designers and shipyards are currently seen as a front-runner in development and implementation of LoZeC energy solutions in shipping industry. Moreover, ship-owners have interested in investment in alternative technologies, and the technology supplier sector for different kinds of alternative solution is growing increasingly. For instance, the cruise company *Hurtigruten* is retrofitting six of the total 16 ships and installing a gas engine to use LBG in combination with LNG which is expected to start operation by 2020 (TU, 2019). Further, Samskip AS is leading a project to develop and realize profitable container transport using hydrogen fuel cells for emission-free propulsion (Moore, 2019).

In terms of various type of LoZeC alternatives, LNG and BE propulsion are two main LoZeC technologies which were used the most (Norwegian Government, 2019). In 2000 the world's first LNG powered car ferry *MF Glutra* started operation, and the number of LNG-powered car ferries in Norway increased to 21 in 2018 (Sandvik, 2018). Moreover, a similar development contract resulted in the world's first fully BE car ferry *MF Ampere* operation in 2015, and by 2022 it is expected to be at least 73 BE ferries in operation in Norway (Staten vegvesen, 2020). The zero-emission vessel *Future of the Fjords,* the world's first all-electric sightseeing vessel (Norwegian Government, 2019). The Staten vegvesen established a project in 2017 with the ultimate goal of demonstrating, and putting into regular operation, a hydrogen-electric ferry by 2021. This project will connect the national road 13 between Hjelmeland – Skipavik – Nesvik in Rogaland from 2021 (Staten vegvesen, 2020). Moreover, the world's first operational hydrogen-powered ferry, the MF Hydra ferry (Linde , 2021), and the world's first liquid hydrogen fuel cell cruise ship (Radowitz, 2021) are of the first hydrogen-powered vessels which will be added to the fleet in near future.

Despite increasing interests in climate-friendly solutions, most of maritime vessels still run on fossil fuels (i.e. diesel or crude oil), and LoZeC technologies have minimal roles in the maritime sector currently (Markus Steen et al., 2019). Moreover, the modest proportion of LoZeC vessels in the order book highlights there are still more orders for conventional ships (Norwegian Government, 2019). In sum, it can be assumed that there is a lock-in in fossil fuels in maritime industry.

A number of different LoZeC technologies could participate in the transition to the green shipping in the NMSS, comprising BE, biofuels, hydrogen, various hybrids of these and/or fossil fuel, etc. Considerable differences between various categories of vessels in Norwegian shipping industry leads to different needed measures to encourage the phase-in of LoZeC solutions (Norwegian Government, 2019). Despite their various environmental benefits, all of these technologies are at the niche stage. Against this summary, in the next sub-sections I focus on the hydrogen niche and its interactions with the established regime. More specifically, to evaluate the role of the sociotechnical landscape changes on the established regime and their interactions with the hydrogen niche in NMSS.

4.1.2. The sociotechnical landscape

In the context of this thesis, the sociotechnical landscape consists of some slow-changing factors like increasing climate change awareness and the long-term changes in national and international climate policies and emission targets as a ‘disruptive change’ which have root in energy security and climate security. Further, the Covid-19 pandemic can be mentioned as a ‘avalanche change’ while reduction in fossil fuel price and increasing unemployment rate in Norwegian petroleum and maritime sectors should be considered as a ‘specific shock’.

4.1.2.1. Disruptive changes

The sociotechnical landscape disruptive changes in the context of this thesis are mainly influenced by national and EU's energy transition policies which have root in energy security and climate security.

Energy security concerns grow because of the path dependency on the finite sources of natural gas in the maritime sector which can lead to a transition to fossil free sources. The Norwegian Petroleum Directorate (NPD) estimates natural gas reserves will last until 2036 in a hypothetical situation where all the discovered natural gas resources extracted (Norwegian Petroleum Directorate, 2019c). Hence, it can be discussed that the change in the Equinor company name from 'Statoil' in 2018 could be a strong signal to the existing regime actors to start phasing out sailing the fossil-powered vessels (Equinor ASA, 2019). Equinor not only changed its business portfolio to a broad energy company (Equinor ASA, 2019). For instance, Equinor is currently partnering in a project for converting Vattendfll's Magnum gas power plant in Netherlands to blue hydrogen-powered plant (equinor ASA, 2017). Moreover, it has invested heavily in developing CCS and offshore wind technologies which could be utilized in hydrogen production (Equinor ASA, 2019). As such, it could be discussed that dependence on fast depleting petroleum reserves is one of the key motivations for increasing attentions to renewable resources like hydrogen in NMSS.

In terms of climate security, increasing scientific evidence of the anthropogenic climate change threats led to the quicken public climate change awareness and growing pressure from climate activists in Norway. For instance, seven out of the nine Norwegian youth party organization which representing the political parties supported the gradually reduction or elimination of petroleum activities (Adomaitis, 2019). Increasing awareness about climate change, particularly among youths is seen as driver for the acceleration of efforts to reduce GHG emissions: '*The vote, people and the lobbying of organizations. I think if there are no (political) pressure groups for clean and* *standards (fuel) so there needs to be protests from people to make it happen quickly'* (Informant 7). Furthermore, publicity and widespread climate strike movements have led to declaration of climate emergency by top politician leaders, particularly the European Parliament (The European Parliament , 2019). Although, the declaration is not binding, it could imply more pressure for reduction in the fossil fuel extraction and enhancing green shipping prospect in regional strategies.

According to informants, rising carbon tax and prices are one of the key mechanisms which have steadily influenced the established regime. '*the other way to show their support on these zero emission projects and solutions is the carbon tax on fossil fuel. In the climate plan they steadily going to increase the carbon tax year by year, and that will affectively make the operational cost of the fishing boat more and more expensive if they just use diesel or natural gas, and so that will make the business argument about using hydrogen vessels or ammonia vessel is better because you are not going to pay carbon tax*' (Informant 1). As of 1st Jan 2018, the standard carbon tax rate on marine oil was increased to 499 NOK/tCO_2e (Energifakta Norge, 2017) and will increase by 5% per year from 2020 to 2050 for all sectors (Norwegian Government, 2019). As such, sailing fossil-powered vessels is getting less cost-effective slowly but steadily.

The European Union (EU)'s decarbonization strategies are one of the disruptive changes which would influence the established regime indirectly but progressively. The EU, as the front-runner at the international climate actions, has a great ambition to become carbon neutral by 2050 compared to the 1990-level, which is compatible with the Paris Agreement goals (European Commission, 2014). The EU's coordinating policies to phase-out of fossil fuel in the energy system and switching to LoZeC solutions (European Commission, 2014) are one of the main drivers for transition to hydrogen for two reasons. First, as part of EU's climate goal to become a carbon-neutral economy, the European Green Deal program is adopted which driving a strong demand for hydrogen due to deep decarbonization in transport, building and industry sectors. Second, the EU climate and Energy framework targets, unlike the Paris Agreement, are binding for the members (UNFCCC, 2019; European Commission, 2014). If so, Norway's petroleum industry faces great uncertainties since the EU is the major market for the oil and gas resources (Norwegian Petroleum Directorate, 2019a).

4.1.2.2. Specific shock

The Norwegian maritime industry is influenced by factors like economic recession and oil price. The collapse of the oil price in 2014 was a specific shock which led to uncertainties over the future of oil and gas industry and an unprecedented peak at unemployment rate in both maritime and petroleum industries, as well as great reduction in turnover in Norwegian maritime sector from 2014 to 2017. Although NMSS has faced very demanding times since 2014, LoZeC solution were used to solve this challenge by regime actors. Research revealed that significant increase in the low-carbon maritime not only compensate for income loss (Norwegian Shipowners' Association, 2021), but will adjust the existing regime with increased demand for green solutions. Hydrogen technology, particularly blue hydrogen as symbiotic technology for existing regime would implement to solve challenges while stabilizing the regime. Some signals of these uncertainties about the future of oil and gas industry which lead to setting up hydrogen development projects were observed in interviews: '*Our initiating motivation for starting a hydrogen development project is to keep the jobs for a long time into the future. Although there have been major waves of attraction to hydrogen previously*' (Informant 4).

4.1.2.3. Avalanche change

Data gathering shows the unprecedented COVID-19 crises has a dual impact on the hydrogen sector. Some believe that COVID-19 outbreak may cause significant delay to adaptation and commercial rollout of hydrogen. As the world faces economic fallout due to COVID-19 crisis the

Governments globally have faced dilemma of kick-starting their climate-friendly planned projects or focusing on immediate challenges regarding the pandemic: '*the political focus is shifted to setting the COVID problem increase and everything and all focus I think are on health; it needs attention, political attention*' (Informant 1). The Hydrogen Europe Analysis outlines that the COVID-19 pandemic not only can undermine the competitiveness of investment in hydrogen technology but also may endanger the movement towards transition to clean hydrogen (Hydrogen Europe paper on the hydrogen sector after Covid-19, 2020).

Conversely, others argue that the Covid-19 pandemic gave a chance to hydrogen technology and can push the market towards the development of a hydrogen economy: '*At the time prior to Covid-19, earlier at 2020 and 2019 one of the biggest barriers was political will from national government or regional government. They didn't want it. But when the pandemic arrived and they begin think on how we are going to restart the economy into a green recovery; they began to really take interest in hydrogen and what role will play in future of energy system*' (Informant 2). According to the EU's strategy document, it planned for accelerating the decarbonization program, and introduced hydrogen as the main driver of economic growth to overcome recession caused by COVID-19. Further, the Norwegian Government's hydrogen strategy shows an increased focus on hydrogen in Norway in line with EU's strategy. In this regard, government presented a crisis package to the parliament in May 2020 which announced a growing focus on hydrogen related research and technology development in order to meet the economic outbreak challenges (Norwegian Ministry of Petroleum and Energy & Norwegian Ministry of Climate and Environment, 2020).

4.1.3. Hydrogen niche-innovation

Hydrogen is classified as one of the most relevant low and zero-carbon fuels for domestic shipping in Norway but as an energy carrier can be seen as ‘niche technologies’ (Ministry of Climate and environment, 2017). Hydrogen can be an option to replace fossil fuel for energy intensive vessels, sailing in long distances between ports, and for vessels with limitations in terms of weight and energy storage. Initially hydrogen is a suitable solution for high-speed ferries, and vessels that are used on scheduled routes, specifically, routes between a small number of port (Ministry of Climate and environment, 2017).

Despite all the advantages of implementing the maritime hydrogen technology, it is currently implemented in pilot projects in local scale due to its higher cost and lower technological performance rather than marine diesel (Steen et al., 2019). Moreover, research shows that hydrogen is seen as a complementary solution for BE currently either as hybrid technology with BE systems or for vessels which electrification is not a proper solution for them (Steen et al., 2019). *‘In the wider picture all the vessels would be electric and they already are electric. Smaller vessels and short distances like most of the ferries for instance would have only batteries but if the ferries are big and the distances are long to travel so batteries are not very perfect, they are very heavy and takes a lot of space so specifically for big ferries and longer distances means too much room and weight is added’* (Informant 7).

In general, hydrogen niche is recently emerged and has fundamental differences with the established regime which means maritime hydrogen technology is not mature in different part of the value chain (see figure 10) including production, distribution, storage, conversion and application. Due to uncertainties about the design and functionality in different part of the value chain, it faces with various challenges in the way of de-stabilizing the established regime and transition. Some dedicated actors from the inside or outside the regime protect the hydrogen niche to support it in breaking through the existing regime. So as to achieve to an in-depth and detailed understanding of the hydrogen niche value chain, actors, and institutions, the TIS analysis of maritime hydrogen technology was adopted and the results are elaborated in the next sub-section.

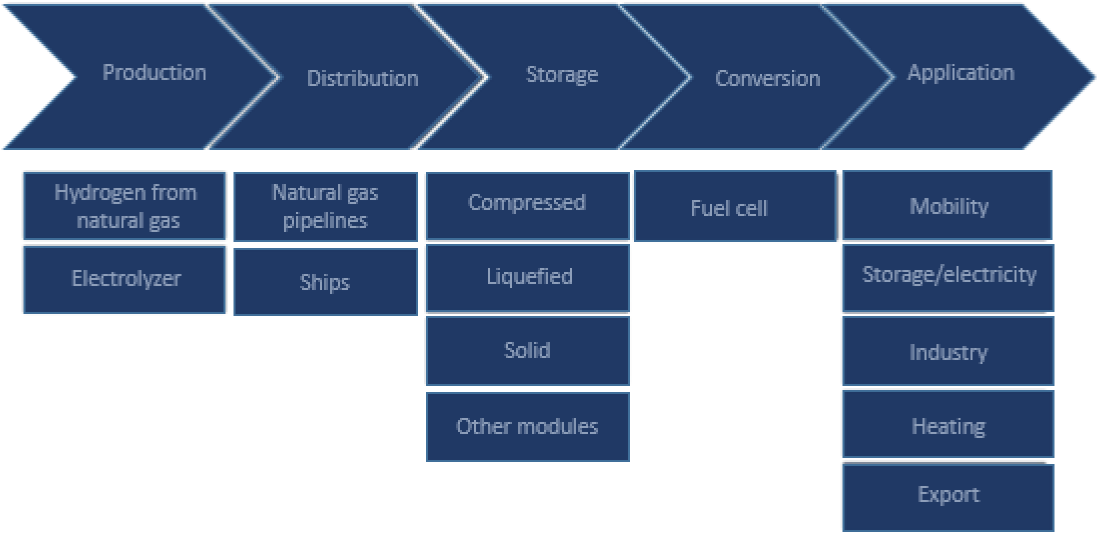


Figure 10. The marine hydrogen value chain starts with hydrogen production which categorized the produced hydrogen in two different type, i.e. blue and green hydrogen based on the used natural resources and production method. Hydrogen could be stored in different storage modules, and could be used in different sectors in addition to maritime sector.

4.2. Evaluating the green and the blue niches using TIS

4.2.1. Niche actors

In the case of Norway, the transition from fossil fuels to hydrogen as an energy career has been focused by government, companies and local industrial groups. Hydrogen demonstration projects are collaborations between different partners comprising government agencies, fuel and technology providers, potential users. Niche-actors' interplay, socialization and institutionalization can lead to knowledge development and diffusion as well as establishment of technological and economic rules and regulations (Geels, Green, & Elzen, 2004). In the case of maritime hydrogen technology, niche-actors at the upstream of the value chain differs considerably for blue and green hydrogen while the downstream parts of the value chain include the same type of actors.

Staten vegvesen is one of the key actors incubating hydrogen niche at the downstream of value chain by incentivizing and promoting real-world maritime hydrogen experiments which will present a possibility for adjusting the demand side design and functionality. Hence, Staten vegvesen participates in establishment of best practices and the technology improvement indirectly. It contributes to many different mechanisms including resource mobilization, legitimacy, market formation, knowledge development and diffusion through the hydrogen road ferry development contract: *'The contract is very important to reduce the risk for the ship-owners, it's a 20-years contract which is very long rather than normal and so by having this very long contract it massively reducing the risk for the ship designer and ship-owner'* (Informant 3). Moreover, the development contracts can increase the possibilities for receiving financial support and improving the resource mobilization flow when the technology is established (Steen et al., 2019). As such, it could lead to enhancement in both supply and demand side of the value chain: '*the boats or ship-owners don't want to sail any boats that go on hydrogen where hydrogen is not available, and then hydrogen production people don't really want to build hydrogen infrastructures unless the hydrogen powered boats become available, they both are waiting for each other for making decision*' (Informant 1).

As illustrated in figure 10, several financial schemes and programs under the Research Council of Norway and Innovation Norway contribute in national funding including Innovasjon Norge, Enova, NOx-fondet, and KLIMASATS. NOx-fondet operates in agreement with the Ministry of Climate and Environment. Enova is an important funding agency is directed by the same ministry, and about one third of Enova's budget is used for transport projects and of this the largest share is for maritime activities (The Norwegian Public Roads Administration, 2020). Innovasjon Norge provides support services to innovative projects related to green shipping and provides loans for a wide variety of projects (Norwegian Government, 2019). Enova, Innovasjon Norge and Forskningsrådet have created PILOT-E, a common support program to support the development of new environmentally-friendly solutions and their introduction to the market (Enova, 2020).

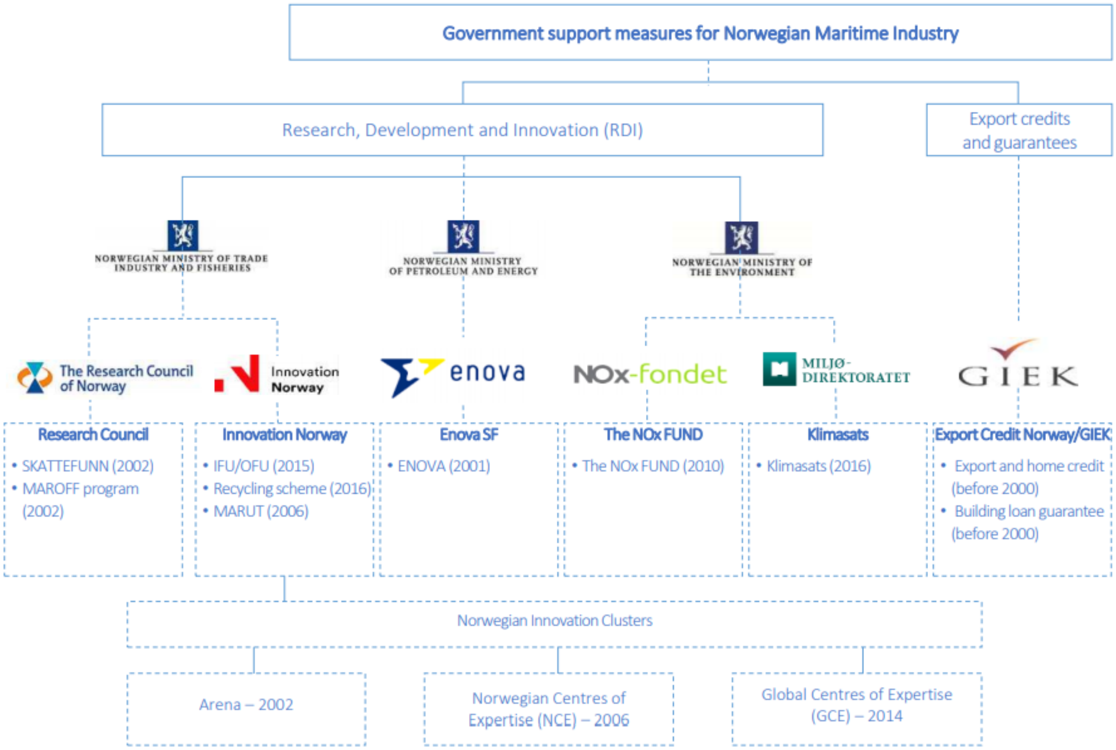


Figure 11. Government's support for Norwegian maritime sector (Koilo, 2020).

National clusters like Ocean Hyway Cluster (OHC) and associations like Norsk Hydrogen forum (NHF) who are focusing on the hydrogen maritime niche play substantial role in stepping forward in hydrogen development. During the interviews it was highlighted a number of times that participating in the cluster was especially important due to its advantages for members by facilitating networking, influencing policy and regulations, and increasing knowledge: '*what Ocean Hyway Cluster do is collaboration with research and education and also political lobbying we got very pleased contacts, and it's like connection point between industry and politicians*' (Informant 4).

Grønt Kystfartsprogram[5] is a partnership program between private and public actors and its network is mainly consist of ship-owners, suppliers and county municipalities. The program is administrated by the classification and consultancy company DNV, and has an ambition of establishment of an efficient and environmentally friendly shipping by focusing on LoZeC solutions and conducting pilot projects and scoping activities. Private classification company DNV provides rules and legislations to guide the development process (Steen et al., 2019). Rules and regulations are necessary for commercialization in a niche environment and without them the novelty may still emerge but will not flourish (Geels, Green, & Elzen, 2004).

Norway has long history in large-scale hydrogen production using electrolysis which dates back to 1920s where hydropower electricity was used for ammonia production during the pre-petroleum era. In fact, NEL (previously the hydrogen electrolyser division of Hydro, NHEL) and YARA (previously Norsk Hydro) are the key actors in hydrogen production using electrolyser technology in Norway. However, in 1980s they switched from electrolyser to steam methane reformation (SMR) for large-scale ammonia production which led to the incorporation of NHEL as a subsidiary of Hydro in 1993 (Koefoed, 2011). Today NEL is the largest electrolyser producer and YARA is the largest ammonia producer in the world (Nel ASA, 2019). Knowing that the produced hydrogen was supplied for industries like agriculture and electronics- and is still does (Yara International ASA., 2019), both YARA and NEL are assumed as external incubating actors for maritime hydrogen niche. Furthermore, in anticipation of the demand for Hyundai hydrogen trucks, NEL established Green H2 Norway joint venture with Greenstat, H2 Energy and Akerhus in 2019. Green H2 Norway plans to be the large-scale producer of green hydrogen (Nel ASA,

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[5] literal translation: 'The green coastal shipping program' (GSP)

2019). Hence, the green hydrogen development in Norway is likely to be rely on niche-actors from outside of the regime such as Yara and may gain more support from Green H2 Norway.

Equinor, is the other essential actor because of its excessive impact on Norwegian energy system and policy not only on the existing regime but also on both blue and green hydrogen. Blue hydrogen, as a symbiotic niche, may gain strong support from Equinor. On the other hand, considering Equinor's investments in floating offshore wind turbines development in Norway, Equinor could potentially be one of the green hydrogen niche actors in long-term. However, it is expected that floating offshore turbines reach maturity from 2040 onwards (Equinor ASA., 2019).

4.2.2. The function analysis

The functional analysis covers seven essential mechanisms, including knowledge development and diffusion, direction of search, entrepreneurial experimentation, market formation, legitimation, resource mobilization, and development of positive externalities. Analyzing the maritime hydrogen TIS functions could be helpful for mapping the drivers and barriers within the maritime hydrogen TIS, particularly by highlighting the functional distinctions of blue and green hydrogen.

The first analyzed function is the knowledge development and diffusion which is typically assumed as the core of the TIS assessment since it contributes in the knowledge basis of the all seven functions (Bergek et al., 2008). According the interviews and previous research (Steen et al., 2019), there is a primary knowledge base regarding hydrogen technology currently. Further, there are gaps in the rules and regulations in all parts of the value chain which was reported as of central prerequisite in the way of maritime hydrogen development projects: '*I would like to have a value chain support program which is involved different aspects including infrastructure, the facility maintenance, security and safety of the producing facilities and plant, transportation challenges especially its cost, hydrogen storage, etc.'* (Informant 2). Hence, additional knowledge development throughout the entire value chain and large-scale testing of maritime implementation of hydrogen is necessary.

Produced hydrogen from different resources can be labeled as green depends on the energy resources utilized for electricity production and priorities of each country, varying from renewable energy sources or low-carbon sources including nuclear and CCS (Staffell et al., 2019). '*This is a big bug, they actually had seen that the energy mix is not good because some of the electricity power is made by coal, nuclear power, and other non-renewable energy sources. We have to revise the definition of what we mean with clean hydrogen'* (Informant 3). Therefore, establishment of a standard for green hydrogen agreed with the EU would pave the way of green hydrogen export while provide a possibility for revising some specific hydrogen production technologies which are labeled as blue currently.

Regarding the resource mobilization, several financial schemes and programs support the both blue and green hydrogen technologies, although there is a lack of the human capital regardless the hydrogen type. Aligned with the need for knowledge development and diffusion in maritime hydrogen technology, education of on-board personnel, who are skilled in the maintenance and operating new systems, is assumed necessary: *'I think we need to start recruit and teach students for this new field, and also people that do the ordinary work not only the students but also the people who are going to build the vessels, maintain the trucks, do the electricity works related to hydrogen'* (Informant 6). Furthermore, some interviewees claimed that the lack of knowledge about maritime hydrogen projects among the public authorities and investors is slowing down the progress: '*It's challenging with the local authority. Because we are the first runner and we move into a new business. We see that there is a lack of knowledge, we have to tell the authority this is how we want to do it, this is how we see it, they don't have the knowledge, and it seems sometimes* *that they do have to go through our education level themselves*' (Informant 3). At the niche level, as different actors interact with each other and the new technology, new rules and practices would develop in a process of learning-by-doing. However, none of these two above stated functions send a strong signal regarding one of the blue or green hydrogen in Norwegian maritime TIS.

The other essential function is legitimacy, which is key to the successful application of a novelty since it attracts new actors, investors and leads to resource mobilization (Bergek et al., 2008). Increasing legitimacy was observed during interviews and previous studies (Steen et al., 2019), particularly due to the increasing interests among main actors to invest and investigate in hydrogen technology was witnessed. However, increasing the climate change awareness may couple with the gloomy outlook of the petroleum industry and cause to stronger legitimacy for the green hydrogen.

Entrepreneurial experimentation is one of the essential functions due to reducing uncertainties about the maritime hydrogen technology and its function within the TIS (Bergek et al., 2008). In the context of this thesis, the focus of entrepreneurial experimentation is in the downstream of the value chain including application, conversion, and storage. The competition around Statens vegvesen's new hydrogen road ferry contract is the most highlighted motivation for hydrogen technology development and experimentation in maritime sector. However, as it is mentioned earlier, the hydrogen road ferry contract is not specified implementation of a specific type of maritime hydrogen i.e. the blue or green hydrogen.

At present, the overall market formation of maritime hydrogen is limited to the pilot projects at the local scale due to users' hesitance about the availability and its higher price rather than conventional marine fuel. So far, hydrogen pilot projects have been initiated at the Western Norway coast because of a potential market for vessels from different categories and having access the established sailing routs: '*We are locating right on the coast out in the ocean and there is a lot of high speed passenger vessels that go up and down the coast into and around the islands and it is interesting, so that's why have worked on for the longest period*' (Informant 1). Moreover, demands for hydrogen and its by-products in other sectors in west coast might strengthen the market formation mechanisms and the development projects' success: '*The market will be the maritime and the road transport but we also look into industry if there are any industry application it could be utilized for, for example producing biogas. You can use hydrogen to have a cleaner process and better process so that's something we might look into, and also there will be in the future need of hydrogen for industry machines like when you're building roads to have all the and machinery which are running on diesel today but it could be transported to hydrogen, but also important customer or business for us is at the aquaculture industry because they're using power for their plants but also they can utilize the oxygen which is a by-product from the production of hydrogen*' (Informant 5). As such, it is assumed that green hydrogen just may take precedence over the blue hydrogen because of the potential market for the by-product of the green hydrogen production. However, the overall maritime hydrogen market does not show any distinction regarding the type of hydrogen.

While two following functions: '*direction of search*' and '*development of positive externalities*' have influential differences, the above-mentioned functions showed less distinctions regarding the blue and green sub-niches. Therefore, two next sub-sections elaborate these functions in-detail by focusing on the blue and green sub-niches.

4.2.3. Direction of search

In terms of direction of search, political factors generally influence the blue and green hydrogen in the same way, however some differences may strengthen or weaken one of them. In the context of this thesis, some respondents claimed there are not strong signals from the Government directing blue or green hydrogen. This assumption can be confirmed given that the Staten vegvesen's new road ferry contracts do not enforce any of them. In contrast, some argued: '*I think the national strategy is not quite completed, especially related to the green hydrogen. They tend to give priority to the blue hydrogen because of the possibilities to reform the natural gas, that is big business for Norway*' (Informant 5). It is documented that Norway politics are dominated by the petro-industrial complex which means policymakers prioritizes the economic interests of the petroleum industry in decision-making over climate changes concerns (Moe, 2015). Knowing that half of the total value of Norway's export in 2018 was based on hydrocarbon resources (Norwegian Petroleum Directorate, 2019a) can demonstrate the tight relations between the government and petroleum industry actors. Hence, it could be assumed that the Government may influence Norway's economic direction in favour of blue hydrogen TIS.

Carbon taxes is the other strong mechanisms which is directing the search of the hydrogen maritime TIS. Carbon prices and taxes in Norway are apprised to be more expensive than CCS technology, which led to the implementation of CCS in Equinor's Sleipner facility in the North Sea in 1996 (Global CCS Institute, 2018). However, producers in blue hydrogen development projects supposed to pay for both carbon tax and CCS technology which is reported as a key barrier for blue hydrogen TIS: '*You are punished twice. I'm paying a CO2 fees for using the natural gas, and I'm going to pay it once more when I capture it, so this is not fair, so that is something we are expecting to be changed in future*' (Informant 3).

Thanks to abundant water resources, and massive expansion of hydropower plants in the 1990s, Norway has access to one of the cheapest and cleanest electricity in the region.' *What does Norway build on? how did Norway develop to be a modern economy? not because of oil and gas, Norway was built on hydropower*' (Informant 7). It assumes that the electricity generating capacity will raise by increasing precipitation from rainfall and glacier melting. Further, the electricity production from onshore wind powers is predicted to culminate by 2030 after implementing all the approved projects and technical improvement. Although increase in domestic electricity consumption is expected, ample surplus electricity is available for green hydrogen production (Bartnes et al., 2018; Skar et al., 2018).

Currently more than 95% of produced hydrogen globally is based on fossil fuel (IEA, 2015). Norway as the world's third largest natural gas exporter has access to ample amount of natural gas for hydrogen production (Norwegian Petroleum Directorate, 2019a). However, investigations reveal that the total natural gas resources on the NCS[6] begin depleting soon, and all discovered resources can be extracted until 2036 by current production rate (Norwegian Petroleum Directorate, 2019b, 2019c). Further, if the entire undiscovered reserves can be fully extracted at the same rate, it would last until 2052. However, reality shows that, half of Norway's undiscovered petroleum resources locates in a geologically unknown region in the Barents Sea (Norwegian Petroleum Directorate, 2019a).

In light of EU's climate goal to become a carbon-neutral economy, in March 2020 the EU Taxonomy program was published by the European Commission as a classification system for sustainable economic activities and entered into force July 2020. EU Taxonomy is binding and applicable in all member states in order to meet the EU's climate and energy targets for 2030 and obtain the objectives of the European Green Deal by providing appropriate definitions to companies, investors and policy makers on environmentally sustainable economic activities (EU taxonomy for sustainable activities, 2019). However, in its EU-wide sustainable investment classification system, there is not a political agreement on neither includes nor excludes natural gas

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[6] The Norwegian continental shelf (Norwegian: Den norske kontinentalsokkelen)

(EU taxonomy for sustainable activities, 2019). The ongoing debate on classification of natural gas as a possible green investment in the European Commission (Abnett, 2021) may lead to insecurity in scaling up with investment in blue hydrogen.

On the other hand, while the EU Taxonomy program proposed less technical screening criteria for electricity generation from wind power, it determined stricter screening criteria for hydropower which could mean hydropower projects will become more expensive (Norwegian Royal Ministry of Finance, 2020). '*Taxonomy means that European Union is having a challenge because they are negative to Norwegian waterfall, but they have done that and they are also negative to natural gas*' (Informant 3).

Furthermore, aligned with the Paris Agreement goals, the European Investment Bank (EIB), the biggest public bank in the world, decided to reduce the funding for traditional gas power plants, coal and oil projects in 2019. This new policy can re-orient the future markets' by sending signals for starting the phase out of carbon intensive projects and providing more financial sources for climate-friendly energy solutions: '*Financial institutions are coming under increasing pressure to divest from fossil industries, and therefore are looking for low carbon investment opportunities*' (Informant 7). Reducing the fuel funding by EIB impedes the blue hydrogen development, while enabling further investment in green hydrogen (Watts, 2019). In light of that, some believe that the EU's commitment to transition to 'a fully carbon-free' hydrogen strengthens the green hydrogen TIS: *In Europe, they are looking towards the green hydrogen for instance German hydrogen strategy and they are also looking in to importing green hydrogen because they won't be able to produce enough themselves for the high ambitions that they have set for the switch from fossil fuel to green'* (Informant 5). The EU has a medium-and-long-term ambition in its scenario create a potential external market for the green hydrogen (FCH JU, 2019).

4.2.4. Development of positive externalities

Norway's long track record in large-scale production of hydrogen using electrolysis is assumed as a positive point for the green hydrogen pathway (Nel ASA., 2020). Three main types of electrolysis technology at present are: alkaline (ALK) electrolysers, proton exchange membrane (PEM) electrolysers and solid oxide electrolyser cell (SOEC). Of the three electrolysis, ALK is mature for large-scale centralized hydrogen production, however: '*If you use electrolytes, you want to scale up your production from making one-ton hydrogen per day to 20, the blue hydrogen production plant will be 3 times bigger but using electrolysis for green hydrogen production needs 20 times bigger space. So electrolysis is not a very scale friendly technology'* (Informant 2). As such, despite the long history of hydrogen production, the electrolysis technology is used for small-scaled applications mostly (IEA, 2019). However, interviewees believe that the current interests in hydrogen is picking up stream by large-scale production and expansion of its implementation not only in maritime sector but also in other hard-to-decarbonized sectors:' *Norway had tried to talk about hydrogen the last 40 years, but every time they sat on the ground and did nothing but now they want to hear about the value chain not only the technology*' (Informant 6).

Few rivers and waterfalls remains for future exploitation and building new dams in Norway. Coupled with the fact that no large-scale hydropower project has constructed in Norway since 1980s due to worries about public retaliation (Moe, 2015). However, a research in 2017 predicted that upgrading with extension of existing hydropower plants could potentially increase the total capacity 22 to 30 TWh per year (Lia, Aas, & Killingtveit, 2017). Hence, obtaining higher efficiency by upgrading and extension hydropower plants would be one way to strengthen the green hydrogen TIS by increasing the renewable electricity production.

Norway has one of the best wind resources in Europe, however onshore wind power plant developments have been generating 3% of 2018 renewable electricity generation due to lack of sufficient subsidies (IEA, 2017). Furthermore, Norway is positioned as a front-runner in offshore floating wind turbine technology while the seafloor topography makes the bottom-fixed offshore wind turbine installations complicated and expensive. Considering that the floating offshore wind is not technologically mature, the development costs are remarkably higher and not economically profitable (Veie et al., 2019). Therefore, technological achievements and economies of scale in floating wind turbines would lead to raise in renewable electricity surplus and motivating the green hydrogen production.

SMR is the mature technology of hydrogen production which has used since 1963 in Norway. Due to its technological maturity, SMR is likely to be the leading technology for large-scale production of hydrogen in near future (IEA, 2019). The produced hydrogen via SMR can be labelled climate-friendly providing using CCS in combination. Therefore, the interest in blue hydrogen technology is strongly affected by other technologies.

Among energy-related technologies in Norway, CCS has enjoyed strong governmental support and investments close to 1 billion EUR between 2007 and 2012 (Moe. 2012, 2015). Increasing full carbon tax rate made CCS technology more favorable and was a key driver for the investment in it (Global CCS Institute, 2018). CCS is being considered as a commercially available mitigation measure for climate change, and as an alternative for the future continued oil and gas exploitation and export in a carbon-constrained world (Normann, 2017). '*Due to Norway's enormous oil and gas industry and experience with CCS, there is a strong argument from that sector (Norwegian petroleum industry) to use blue hydrogen as it will help the sector transition to a lower carbon future*' (Informant 4). Moreover, CCS is like a political solution which is supposed to integrate various views and makes the governmental coalitions among various parties possible (Langhelle et al., 2017): '*In Norway we have a lot of political parties and all of them are agreed upon those* *five climate goals and all of them believe in the fifth goal which is handling of CO2 which means CCS*' (Informant 2).

Apart from political drivers, Norway has large-scale geological storage sites, and extensive experiments in CCS implementation as a world leader in CCS technology (Storset et al., 2019). However, CCS like many other technological solutions is not flawless. The biggest technical barriers against the utilization of CCS is the large amount of energy needed, which increases the blue hydrogen production cost (Ministry of Petroleum and Energy, 2014): '*There are lots of infrastructures in petroleum industry which make it easy to make blue hydrogen but we looked at that but it's costlier than electrolysis*' (Informant 7). Furthermore, 5 to 10% of all the CO2 generated in the blue hydrogen production process will be leaked, which increases the carbon footprint (IRENA, 2019). As such, further technological advancements of CCS technology would be a game-changer for the blue hydrogen. In this regard, the Government places great emphasis on the realisation of the Norwegian full-scale CCS '*Langskip'*[7] (Ministry of Petroleum and Energy, 2020). Although the attractive advantages of utilizing CCS including significant reduction in the carbon footprint of blue hydrogen production, maintaining the current position of Norwegian oil and gas industry, and boosting the development of blue hydrogen, it may lead to slow down the structural changes that might be beneficial for green hydrogen TIS (Moe, 2015).

In conclusion, clear distinctions between blue and green 'direction of search' and 'development of positive externalities' functions are observed while other functions take no precedence to one of them. According to the TIS analysis, the 'direction of search' mechanism will play as a transition motor and strengthen other functions within the TIS. Moreover, this function not only may steer innovation towards hydrogen technology but also it may facilitate the transition

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[7] In English 'Longship'.

to the blue hydrogen. Accordingly, national and regional decarbonization strategies, natural resource availability, and level of maturity of relevant technologies are considered as the the determining parameters in hydrogen's transition. Moreover, 'rising carbon taxes and prices' is recognised as a strong governmental tools which have positive impacts on green and negative impact on blue hydrogen transition. Further, Staten vegvesen's development contract for a new hydrogen road ferry is the main driver for maritime hydrogen experimentation, as well as knowledge development and diffusion. As a result, legitimacy may increase and spark the emergence of the market. In general, development of positive externalities and market formation are assumed as the weakest functions aligned with previous research (Steen et al., 2019).

Table 3. Summary of the functional analysis of the blue and green hydrogen TIS. The blue and green hydrogen TISs are common in some functions while they are different in the others. So as to distinguish the commonalities and differences in this table the commonalities were written in black while the differences are in red.

TIS Functions	**Blue hydrogen**	**Green hydrogen**
Direction of search	*Enabler:* ‣ Abundant access to natural gas reserves ‣Depleting natural gas resource ‣ Mature technology for hydrogen production via SMR ‣ large-scale geological CO2 storage sites ‣ Public procurement ‣ Deep decarbonization of the EU by 2050 ‣ A growing global demand for hydrogen ‣ A petro-industrial complex ‣ Lower risk of stranded assets *Barrier:* ‣ Rising carbon prices and taxes ‣ The EU Taxonomy ‣ Cutback on fossil fuel funding from EIB	*Enabler:* ‣ Access to ample amount of water and cheap renewable electricity ‣ Pioneer in electrolyser technology ‣ Public procurement ‣ Deep decarbonization of the EU by 2050 ‣ A growing global demand for hydrogen ‣ Rising carbon prices and tax ‣ Cut-back on fossil fuel funding from EIB *Barrier:* ‣ The EU Taxonomy ‣ A petro-industrial complex
Resource mobilization	*Enabler:* ‣ Funding available from both national and EU sources *Barrier:* ‣ Competition with other LoZeC technologies for funding	*Enabler:* ‣ Funding available from both national and EU sources *Barrier:* ‣ Competition with other LoZeC ‣ Shortage of human capital with hydrogen

	‣ Shortage of human capital with hydrogen competence	competence
Legitimation	*Enabler:* ‣ Increasing belief in safety of the technology *Barrier:* ‣ Increasing awareness about the climate change threats leads to actions for restricting the petroleum activities	*Enabler:* ‣ Increasing belief in safety of the technology *Barrier:* ‣ Protests against onshore wind projects
Market formation	*Enabler:* ‣ Public procurement creates a limited market with need for large investments also in production and distribution ‣ Potential market in Western Norway coast ‣ Increasing market for hydrogen as a road transport fuel, and feedstock in heating and industry *Barrier:* ‣ Investors hesitant due to high fuel prices	*Enabler:* ‣ Public procurement creates a limited market with need for large investments also in production and distribution ‣ Potential market in Western Norway coast ‣ Increasing market for hydrogen as a road transport fuel, and feedstock in heating and industry ‣ Increasing market for by-product of electrolysis *Barrier:* ‣ Investors hesitant due to high fuel prices
Entrepreneurial experimentation	*Enabler:* ‣ Staten vegvesen the dedicated actor in the hydrogen experimentation by new road ferry contracts *Barrier:* ‣ Few actors involved in experimentation	*Enabler:* ‣ Staten vegvesen the dedicated actor in the hydrogen experimentation by new road ferry contracts *Barrier:* ‣ Few actors involved in experimentation

Development of positive externalities	*Enabler:* ‣ Full-scale CCS demonstration project underway ‣ World leader in CCS technology	*Enabler:* ‣ Plans for large-scale centralized green hydrogen production plants ‣ Higher efficiency by upgrading and extension of hydropower projects ‣ World's leading developer for offshore wind power
Knowledge development and diffusion	*Enabler:* ‣ Good collaboration between several types of actors within national and regional networks *Barrier:* ‣ Further development and large-scale testing of hydrogen technology is needed ‣ Need for education of on-board personnel for operation and maintenance of new hydrogen systems	*Enabler:* ‣ Good collaboration between several types of actors within national and regional networks *Barrier:* ‣ Further development and large-scale testing of hydrogen technology is needed ‣ Need for education of on-board personnel for operation and maintenance of new hydrogen systems

5. Discussion

5.1. Challenges of maritime hydrogen transition

Despite the different attractive environmental benefits of hydrogen comparing conventional marine diesel, the current considerable higher cost of hydrogen is the main barrier to the implementation of hydrogen as a shipping fuel (Norwegian Government, 2019). Previous studies showed that a sustainable transition to hydrogen in shipping industry hinges on challenges like investment costs, technology development, and availability (Steen et al., 2019) which are discussed in the following paragraphs.

Various financial support mechanisms are designed to stimulate NOx or GHG emission reduction in shipping industry by promoting support to climate-friendly solutions. However, competitions with other LoZeC technologies also among blue and green hydrogen technologies were observed. Some respondents described the processes of getting financial support challenging and unclear: *'I don't know how it would be possible really because it seems that it's difficult to get financial support, we have tried earlier and they said: NO. They (government) have increased amount of funding available to such zero emission projects but the schemes that companies should provide for financial support didn't really work for hydrogen'* (Informant 6). However, they predict increasing political interest to implementing hydrogen in maritime industry will change the financial support policies positively.

More importantly, some interviewees aligned with previous literature indicate that financial schemes and programs often available for R&D projects (Steen et al., 2019): '*A lot of the investment has been in hydrogen R&D side like in the fuel cells or the electrolyzes rather than the vessel or constructing infrastructures side because they are quite sure that it is going to be hydrogen demand. But the technology exists because Europe is far ahead of Norway at the moment. So what we need is support for investing in the infrastructure because it will take time before it's commercially viable*' (Informant 5). More specifically, some interviewees argue that increasing investments in R&D projects related to the downstream of the value chain such as ship design, ports, storage and distribution, as well as users of other potential markets like heavy vehicles can eventually lead to market formation for hydrogen technology in maritime sector: '*I think when you have support for demonstrating the vehicles and vessels running on hydrogen, the rest will follow then that will force the work with regulations on the governmental side that will also kick off more production of hydrogen and the infrastructure'* (Informant 6). Accordingly, previous research is noticed that financial support in the form of favorable loans or guarantee schemes are required in order to reduce risk of investing in carbon-lean ships (Steen et al., 2019). Regarding that the Government recently allocates NOK 85 million to the hydrogen development of infrastructure and markets in the revised national budget for 2021 while NOK 100 million has been allocated to this purpose previously (Regjeringen, 2021).

In terms of application of hydrogen, research showed reducing concerns for the safety and reliability of hydrogen by ship-owners and shipyards led to grow interests and investment in hydrogen technology (Steen et al., 2019). However, lack of rules and regulations regarding safety for implementing hydrogen in maritime sector makes the construction of hydrogen-powered ships and relevant infrastructure costly and time consuming (Steen et al., 2019) which is dampen the market formation: '*The boat designers follow the alternative design which is a regulation that they have to follow it and get approval. So that process is costlier and take more time than a specific certain standard to follow; And it's the same for the infrastructure side because they want to have a kind of alternative design standard which is costlier and needs more time*' (Informant 1).

Furthermore, regulatory gaps and barriers may decline the chance of market formation for hydrogen technology in other sectors like aquaculture, road transport, heating and industries. Parallel increasing interest in hydrogen within these sectors and shipping industry may push both forward, and increase the demand for hydrogen in conclusion. However, considering that Norwegian hydrogen technology is at its early stages, from innovation science viewpoint establishment of in stone rules and regulations might occlude innovation:' *but the challenge is that they don't want to set in stone regulation that will actively block innovation because it is still under development so they don't want to put too strict regulations*' (Informant 1).

In terms of distribution, two transport vessels exist for blue and green hydrogen produced in Norway: hydrogen gas pipelines or ships. For distance below 1500 km, the most economical option is transporting compressed hydrogen gas via hydrogen gas pipelines (IEA, 2019). The upfront capital cost for building a new network of subsea hydrogen pipelines is expected to be more than building new natural gas pipelines. Therefore, it is unlikely that such pipelines will be built unless it can be transported a considerable volume of long-term hydrogen demand (Aarnes et al., 2019). Research showed that adaptation of the existing gas infrastructure for utilizing in blue hydrogen value chain, not only reduce the risk of stranded assets in the natural gas industry (Norwegian Petroleum Directorate, 2019d) but also present an opportunity to blue hydrogen niche.

Given that the distribution cost is of central factor in increasing the hydrogen prices, centralized large scale hydrogen production projects require additional transport and storage infrastructures which is expensive. Hence, it might lead to either increasing interests to small scale production projects near the potential markets: '*If you are small scale producer you could always look for to avoid transports because it's transport of hydrogen which is more, more complicated then you leave the basis of electrolysis which is a nice starting point'* (Informant 5) or encouraging actors who are not able to produce their own demand, particularly users from other sectors, to join the development projects or setting up their site near them*: There's a lot of company hopefully who are wanting to be close to our project. Of course, it's one of the reason for establishing in this area*' (Informant 2).

In terms of storage, hydrogen can be stored in the vast variety of approaches and materials i.e. compressed, liquefied, ammonia, etc. (Niaz, Manzoor, & Pandith, 2015). Efficient and safe hydrogen storage is the key to the hydrogen economy and optimize the production capacity and ensure supply security (Niaz et al., 2015). Although, both hydrogen compression and liquefaction technology are mature technologies (Hart et al., 2015), liquefied hydrogen is not achieved to the cost-effectiveness to store hydrogen at large scale (Niaz et al., 2015). Norway is a pioneer in producing ammonia which is an attractive alternative for storage liquid hydrogen as inter-seasonal storage (IEA, 2019). However, ammonia needs to go through a dehydrogenation process called ammonia cracking before it can be used in hydrogen end-use applications which is not feasible for large-scale conversion (Andersson & Grönkvist, 2019). More importantly, some interviewees indicate that considering different storage modules for hydrogen e.g. liquefied hydrogen, compressed hydrogen, ammonia, etc., there is a big uncertainty about the proper storage module for the different vessels: '*There are different hydrogen technology or products like compressed, liquefied and Ammonia; it's hard to know exactly how the infrastructure and the supply or the demand will look like in the future so that's an expensive risk*' (Informant 4).

In terms of conversion, implementing hydrogen as energy career in shipping industry relies on the use of fuel cells. Fuel cells are one of the most promising renewable energy source technologies in the maritime sector because of their great power production density, efficiency, reliability, and durability (Han, Charpentier, & Tang, 2014). Although several Norwegian actors hold patents fuel cell technology, it is fostered with external actors and the initial research on fuel cell was not specifically for the maritime application, thus it is not mature for utilization in maritime hydrogen niche (Steen et al., 2019). As such, knowledge development and diffusion of maritime-specific fuel cell technology would pave the way for the maritime hydrogen transition.

In terms of production, Norway has ample access to natural resources and cheap renewable energy for hydrogen production and has long history in producing hydrogen (Statkraft, 2018). Although blue and green hydrogen have commonalities in distribution, storage, conversion, and application, major differences in production methods and required natural resources can cause distinctions in their eventual transition pathways. Hence, in this thesis, the TIS method was utilized in order to inform the MLP about the blue and green hydrogen key differences and understanding the challenges of transition to each of them, particularly in terms of production. Utilizing the findings of the TIS method not only answered the second research question but also presented the hydrogen transition pathway in general and green and blue sub-niches transition pathways in particular.

5.2. The prospect of blue and green hydrogen niche transition pathways

The maritime application of hydrogen technology is fairly immature, and it is in its early demonstration phase. Dependence on petroleum industry for economic growth and abundance of green and cheap electricity are the key motivations for increasing attentions to hydrogen in Norway. Despite the increasing interests in hydrogen as maritime fuel and different benefits of using hydrogen in the maritime sector, its application faces challenges in availability, technological development, lack of infrastructure, and investment costs. Although several national actors support the hydrogen niche, standards and regulations have not been formalized yet. It is expected that under a process of learning-by-doing in the development projects and exchanging the knowledge in the networks best practices would be established and the maritime hydrogen technology will improve gradually.

Assessments show that transition to hydrogen require development and scaling up with the technology in all part of the maritime hydrogen value chain i.e. production, distribution, storage, conversion, and implementation. In light of that, the following paragraphs explain how they can participate in the transition in the near future and in the long-term.

In terms of application, it is expected that the first hydrogen-powered ferry and cruise ship will sail in Norwegian water before mid-2020s. Further, an acceleration in the process of commercialization in niche environment can be expected considering the DNV's ambition to establish the rules and legislations to guide the development process (Steen et al., 2019). In addition to shipping industry, parallel interests in hydrogen for application in other sectors, heat, industry and power generation sector (Steen et al., 2019) can strengthen the position of maritime hydrogen niche.

Like any other product, hydrogen must be stored to bring it from production to final use. The imbalance between demand and supply addresses the importance of hydrogen storage which is one of the demanding part of the value chain. Knowing that large-scale hydrogen liquefaction is at nascent stage, it is not expected to play important role in hydrogen transition in the near future. On the other hand, Norway is one of the pioneers in production of ammonia which has relatively low transportation costs. Hence, the liquid ammonia is the other interesting alternative which can be shipped by existing chemical and semi-refrigerated liquefied petroleum gas tankers (IEA, 2019). As such, ammonia and compressed hydrogen are assumed as the promising storage module for the long and short sailing routes respectively at the first phase of the transition before scaling up with the other storage modules like liquefied hydrogen.

Fuel cell is the promising way of hydrogen conversion which in the same way as ammonia is assumed as an add-on technology utilized in hydrogen niche. However, hydrogen as a direct fuel in fuel cells is favourable for short distance navigation such as ferries while open-ocean sailing may rely on liquefied hydrogen or ammonia (Seck, Hache, Barnet, & Guedes, 2021). Both ammonia and fuel cell technologies are emerged in an environment outside the current regime but at the initial phase of the transition may link the niche up with an existing technology as a complement to improve them (Geels, Green, & Elzen, 2004).

In terms of hydrogen transport as it is mentioned earlier, the upfront capital cost for building a new network of hydrogen pipelines is expected to be more than building new natural gas pipelines. Hence, it is unlikely that such pipelines will be built in initial phases of transition for transporting hydrogen in near future. Unless considerable volume of long-term hydrogen demand and technical advancement legitimize the higher cost of hydrogen pipelines. Hence, transporting compressed hydrogen gas in the form of blended natural gas using the existing gas pipelines is the most economical option for distance below 1500 km (Aarnes, Haugom, Norheim, Dugstad, & Ellassen, 2019), and for distances above 1500 km, it could be more cost-effective to transport hydrogen by ship in the form of liquid ammonia than in the form of liquid hydrogen (IEA, 2019). More importantly, utilizing the existing gas pipelines can present an opportunity to the existing regime by solving the risk of strand of assets.

It is expected that a launching the commercial scale LH_2 tanker ship of 160 000 m^3 storage capacity successfully by 2030 (Harding, 2019) can speed up the design and construction of commercial scale liquefied hydrogen. As such, the transport cost of LH_2 is expected to be e USD 2/kg H2, almost double that of liquid ammonia (USD 1.20/kg H2)(IEA, 2019). However, ammonia needs to go through a dehydrogenation process called ammonia cracking which is high energy demanding and not feasible for large-scale cracking currently (NCE, 2019). As such, it could be assumed that from 2030 onwards the liquefied hydrogen might replace the liquid ammonia.

Despite Norway's long track on hydrogen production, current Norwegian production of maritime hydrogen is limited to local production connected to pilot projects on hydrogen ferries (Ministry of Climate and environment, 2017). The TIS assessments illustrates that the upstream of the hydrogen value chain differs considerably, regarding the required natural resources and the technologies which is used for the production. Conversely, the downstream parts of the value chain include the same type of actors participating in storage, distribution, conversion, and implementation.

In the context of Norway, blue hydrogen is assumed as a symbiotic niche-innovation due to its dependence to the existing regime's sources i.e. natural gas and CCS technology. In contrast, green hydrogen would be assumed as a competitive niche-innovation since it is grown originally by actors outside of the regime. As a symbiotic niche, blue hydrogen gains strong support from the current regime and will play role in stabilizing the regime by solving minor challenges which have root in energy and climate security. Besides, it probably benefits from Norway's ample access to natural gas and lower internal natural gas prices. More importantly, blue hydrogen would have advantage over green hydrogen at least in short term considering that natural gas reforming is the dominant hydrogen production method currently. Further, blue hydrogen sub-niche will gain from the special position of CCS technology in Norwegian policy. CCS technology is assumed as symbiotic solution for to the existing regime's problem which not only helps the regime in adjusting with recent decarbonization policies also legitimizes further reliance of the Norwegian petroleum industry. As such, the Norwegian government indicates more attention to the CCS technology which is boosting the blue hydrogen sub-niche.

In light of that Norway has great ambition to launch the first full-scale CCS demonstration project which is expected to commence operations in 2023-2024 (Bellona Europa, 2018). Extensive investments in CCS technology which is the key factor in transition to blue hydrogen is indicated a partial reorientation of the regime where both new and old technologies co-exist with lean institutional changes. More importantly, success in CCS large-scale demonstration project can strongly impact on hydrogen's transition pathway in favour of blue hydrogen in Norway.

Blue hydrogen transition pathway hinges on the access to the natural gas resources in the NCS[8] and achievements in CCS large-scale demonstration projects. The depletion of Norway's natural gas resources persuades Norway to give priority to other opportunities for hydrogen production. More specifically, the increasing carbon taxes and prices and growing climate change awareness among youth in Norway will put the Norwegian petroleum industry under pressure to keep the

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[8] The Norwegian continental shelf (Norwegian: Den norske kontinentalsokkelen)

undiscovered resources in the ground. As such, blue hydrogen at the initial phase plays the role of symbiotic innovation which is developed in the regime to solve problems. Provided that the basic architecture of the existing regime remains consistent, a transformation to blue hydrogen would occur. Under these circumstances, blue hydrogen developments could follow the transformation pathway before 2030 when the existing regime is destabilized.

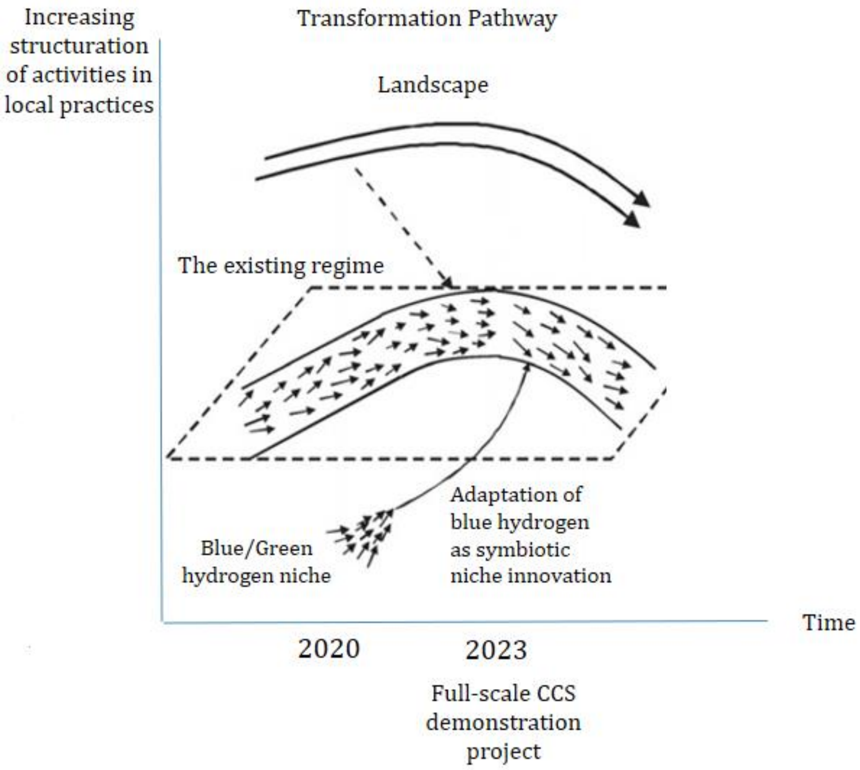

Figure 12. The blue hydrogen niche eventual transition pathway. As a symbiotic sub-niche, the blue hydrogen can be adopted by the current regime to solve its challenges regarding the climate and energy security. As such, blue hydrogen may develop in a transformation pathway while it is not mature yet and the regime architecture is not changed.

However, If the Government decide to make new discoveries of commercial gas fields and delay the inevitable depletion of its reserves to beyond 2050, a second scenario could be predicted. In this case, the adopted niche may require further adjustments as regime pinpoint new opportunities including extraction of natural gas from undiscovered petroleum reserves and advancement in the CCS technology. This process will lead to a reconfiguration on regime’s basic architecture by more combination between old and new elements, changes in system components and relation, as well as user practices. However, in this potential trajectory not only there is risk of not finding commercially viable well in undiscovered petroleum resources but also constructing the required infrastructures for extraction process can lead to additional investments as well as higher production cost.

On the other hand, there are abundant of the natural resources i.e. water and RE electricity for green hydrogen production in Norway. At present, the small-scale green hydrogen projects can take advantageous of hydropower electricity surplus, mature production technology, potential market for by-product in aquaculture industry, and lower cost of production via electrolysis. As a result, not only they play role in knowledge development and market formation but also influence the eventual transformation trajectory. As mentioned earlier, the prospects of green hydrogen production depend on advancement in electrolysis technology and electricity generation capacity which are expected to reach the peak in near future. Hence, majority of the green hydrogen is expected to produced using water electrolysis from 2030 onwards in the lower cost rather than blue hydrogen (FCH JU, 2019). As such, the scope of more new blue hydrogen installations can be narrow from the mid-2030s. The green hydrogen installation costs are expected to be 70% lower than today's costs in 2050 and the cost reduction will correspond to a reduction in installed cost due to higher learning rates, large future investment particularly in electrolysis technology (Seck et al., 2021). However, a complete change in the regime may take place when the old technology (blue hydrogen technology) is replaced by green hydrogen, one would expect substantial institutional changes (Frank W. Geels & Schot, 2007). By closing the window of opportunity for investments in blue hydrogen, that of renewable hydrogen opens to destabilize the new regime for the second part of the transition. To make advantage of the window of opportunity, reduction in investment in blue hydrogen projects by mid-2020s is expected, aligned with national and international carbon neutral policies like carbon taxes and prices. Equinor is expected to participate in green hydrogen development from 2040 onwards when floating offshore wind turbines are commercially mature. If so, the new regime will adjust itself with new circumstance.

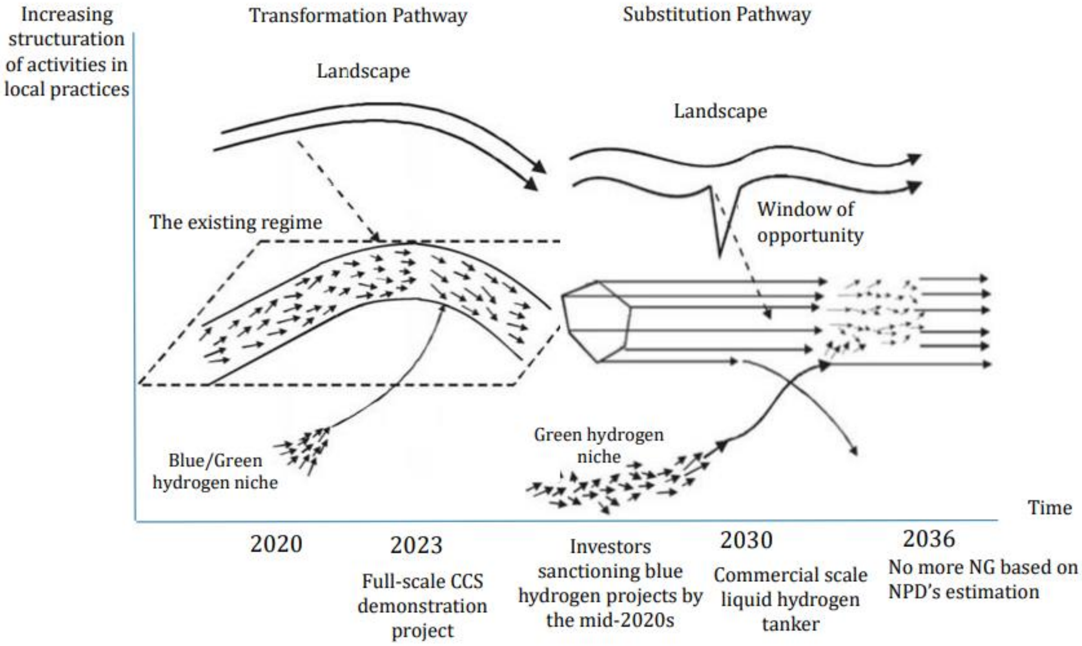

Figure 13. The Blue and green hydrogen transition pathways. A complete change in the regime may take place when the blue hydrogen technology is replaced by green hydrogen due to a window of opportunity. To this end, the green hydrogen sub-niche supposed to be enough mature for competing with the established regime.

Although, Norway has a long history in producing hydrogen via water electrolysis, development of green hydrogen technology is incubating by actors outside of the regime such as Yara (in case hydrogen would be used as ammonia), NEL and Green H2 Norway. Hence it may indicate that the substitution pathway has great relevance to green hydrogen transition. A window of opportunity for green hydrogen would provide the chance to appear in the dominant regime and compete with blue hydrogen in order to achieve more cost-competitive price and improvements in availability. It is expected that as Norway prepares for reducing oil and gas exploitation by 2030, a window of opportunity opens up for obtaining revenues by exporting green hydrogen. As such, in a substitution pathway, the green hydrogen may eventually take the position of blue hydrogen. Against this discussion, table 5 is summarized the key drivers affecting the blue and green hydrogen transition in Norwegian maritime sector at the landscape, regime and niche levels.

Table 4. The MLP perspective of blue and green hydrogen transition in the context of Norwegian maritime sector.

MLP levels	Key factors
Landscape	Disruptive changes: • Deep decarbonization of the EU • Rising carbon prices • The EU Taxonomy program • Cutback on fossil fuel funding by EIB • Rising climate change awareness among youths in Norway Specific change: • The collapse of the oil price in 2014 Avalanche change: • COVID-19 pandemic
Regime	• Depletion of natural gas resources from 2023 onwards • Strong uncertainty over the future of oil and gas in Norway by 2023 • Diversification of portfolio by incumbents • IMO environmental obligations • The government action plan for greening the fleet
Niche	• At present maritime hydrogen technology is limited to pilot development projects at local scale • A mix of blue and green hydrogen before 2030 • Green hydrogen production technologies currently appear to reach maturity by 2030 • Infrastructure for hydrogen particularly storage and distribution may be ready in 2030 • Green hydrogen is expected to be more price-competitive than blue hydrogen by 2030

6. Conclusion

According to the analysis, it could be interpreted that increasing climate change awareness and the long-term changes in national and international climate policies and emission targets are the most influential landscape changes which have root in energy security and climate security. In the context of Norway, hydrogen is considered as a promising solution for NMSS to maintain its function while reducing its environmental burdens due to hydrogen's ubiquity and versatile applications across sectors. Norway is well-positioned for implementation of hydrogen in maritime industry in terms of natural resources availability, existing compatible infrastructures and technological expertise for the development of hydrogen. Hence, hydrogen is expected to play an essential role in carbon-lean energy system in the foreseeable future. However, hydrogen niche would need to be implemented in a mature, highly heterogeneous, and multi-segmented sector which has a path dependency to the fossil fuels. Most vessels in NMSS still sail on fossil fuels and the green solutions have the modest role in the regime currently despite the incremental innovations in the design of vessels. Evidences show that far-reaching transformation in NMSS towards implementing hydrogen is not possible only by technological achievements, and transformation in NMSS as a sociotechnical system depends on a cluster of elements, including user practices, policy, infrastructure, financial supports, rules and regulations.

Findings show that financial support programs, R&D projects, policy initiatives, complementary technologies, potential market, and dedicated actors and networks are drivers for the large-scale implementation of hydrogen in NMSS. However, transition to hydrogen technologies in Norwegian maritime sector cannot be accomplished unless by knowledge development and diffusion in all parts of the maritime hydrogen value chain, establishment of new regulations and standards, building new infrastructures and adaptation of existing one, as well as promoting new types of actors. In this regard, some mechanisms are assumed more influential in speeding up the NMSS transformation towards maritime hydrogen. First, increasing demands for hydrogen-powered vessels in public procurements can act as a driver for the downstream of the value chain. Analysis shows, it can lead to market formation, increasing legitimacy, creation of economic competition, and development of technical trajectories and actors' network. Second, supporting large-scale development projects can speed up the knowledge development and diffusion as well as lowering the hydrogen fuel price in order to become a realistic alternative. Third, updating the rules and standards relevant the entire value chain, particularly establishing a classification of hydrogen ships can reduce uncertainties and strengthen both the demand and supply side in a tandem mechanism.

Overall, hydrogen-powered vessels may rely on mix of blue and green hydrogen in the foreseeable future. In the context of Norway, blue hydrogen is assumed as a symbiotic niche-innovation due to its dependence to the existing regime's sources i.e. natural gas and CCS technology. As such, transition to blue hydrogen hinges in the achievements in large-scale CCS demonstration project in Norway. However, it is predicted that the transition to hydrogen in Norwegian maritime industry may initiate when blue hydrogen re-adjusts the existing regime. Blue hydrogen as symbiotic niche allows Norway to retain its petro-industrial complex and can solve the challenges of current regime due to landscape changes.

In contrast, green hydrogen would be assumed as a competitive niche-innovation since it is grown originally by actors outside of the regime. Access to cheap RE electricity, ample amount of water, potential market for the by-product, and available production technology has been beneficial for the local scale green hydrogen. Although, large-scale green hydrogen production is still immature, increasing interests in small-scale green hydrogen projects may be advantageous for its role in the eventual maritime hydrogen pathway. The role of green hydrogen in a low-carbon marine energy system is likely raise by depleting Norway’s discovered natural gas reserves. Depleting natural gas resources may open the window of opportunity for the green hydrogen which get matured in a learning-by-doing process. To make advantage of the window of opportunity, reduction in investment in blue hydrogen projects by mid-2020s is expected, aligned with national and international carbon neutral policies like carbon taxes and prices. Moreover, the green hydrogen installation’s cost is predicted to be 70% lower than today’s costs in 2050, hence the number of blue hydrogen projects may not increase from 2050 onwards.

6.1. Recommendation for future research

Given the complexities in the value chain and various vessel categories, this study’s framework is limited its focus on to the blue and green hydrogen. A deeper understanding of the maritime hydrogen transition by focusing on downstream of the value chain, particularly various forms of hybrid systems, specific categories of vessels and/or various hydrogen storage modules would be useful.

Norwegian west coast with established sailing routs and active ports has great potential for development of energy hubs. According to the Government’s action plan for green shipping, substantial emission reduction in most vessel categories can be achieved by various forms of hybrid systems (Norwegian Government, 2019). Having more climate-friendly vessels using different LoZeC propulsion systems, various forms of hybrid, and different storage modules means more storage, distribution, and re-charging facilities are required. Accordingly, it would be valuable to analyses the capability of improving ports to an energy hub in Western Norway by evaluating the supply chain visibility, possibility of having the compatible and complement production lines in one site, and the potential demands in the shipping industry and from other sectors.

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8. Appendix

8.1. Appendix 1

Location	Initializer	Start year	Production type	Source
Glomfjord	Nel ASA, Greenstat AS and Meløy Energi AS (LH2 HyInfra)	2024	Electrolyser	glomfjordhydrogen.no
Mo i Rana	Statkraft, Celsa & Mo Industrial park	2023	Electrolyser	Nelhydrogen.com
Finnsnes	Statkraft & CRI	2023	Electrolyser	statkraft.com
Mongstad	BKK, Equinor & Air Liquide, and other (LH2 HyInfra)	2024	Electrolyser	BKK.no
Mongstad	A future SMR plant is assumed		SMR	
Kollsnes, Øygaarden	CCB & ZEG Power	2022	SER – demo	zegpower.no
Hellesylt	Hellesylt Hydrogen Hub	2023	Electrolyser	hyon.no
Berlevåg	Varanger kraft (LH2 HyInfra)	2020	Electrolyser	varanger-kraft.no
Florø	HyFuel	Construction starts 2021	Electrolyser	incgruppen.no

8.2. Appendix 2

Are you interested in taking part in the research project?

”Hydrogen in the maritime sector in Western Norway: Evaluation of production and implementation in a value chain”

This is an inquiry about participation in a research project where the main purpose is to contribute to the hydrogen technologies transition debate by analysing its technology innovation system in Norway maritime sector and is affiliated with the Norwegian Centre for Energy Transition Strategies (NTRANS) research project. In this letter I will give you information about the purpose of the project and what your participation will involve.

Purpose of the project

The research project is a master thesis in Climate Change Management and investigates the challenges and benefits of transition to hydrogen as an energy career and its implementation particularly in maritime sector.

Who is responsible for the research project?

I am, together with my university, Western Norway University of applied sciences (HVL), responsible for the project.

Why are you being asked to participate?

In order to answer my research question, I aim to conduct semi-structured interviews with at least one participant of the firms and companies who are involved in two selected hydrogen projects: Hellesylt Hydrogen Hub and CCB Energy Park. This is why I have contacted you. I have in total contacted 8 firms.

What does participation involve for you?

If you chose to take part in the project, this will involve that you:

- participate in an online interview, which will take approx. 45 minutes. None of the questions will be of sensitive character, but rather of your general thoughts on hydrogen production and implementation.
- agree to conduct the interview over zoom (or other digital solutions that fit you better). I furthermore hope to record the interview in order to be able to transcribe the recording afterwards.

Participation is voluntary

Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no negative consequences for you if you chose not to participate or later decide to withdraw.

Your personal privacy – how I will store and use your personal data

I will only use your personal data for the purpose specified in this information letter. I will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act).

- I am the only person who will have access to the recording and data connected to the interview.
- I will replace your name and contact details with a code when handling the data. The list of names, contact details and respective codes will be stored separately from the rest of the collected data. I will store the data on an encrypted research server.
- The participants will be anonymized and therefore not directly recognizable in the thesis. However, it will be clear that you are the representative of a specific firm/company.

What will happen to your personal data at the end of the research project?

The project is scheduled to end 10/6/21. By the end of the project, I will delete all gathered data from the research server. However, the thesis will be published on an internal research server of the university.

Your rights

So long as you can be identified in the collected data, you have the right to:

- access the personal data that is being processed about you
- request that your personal data is deleted
- request that incorrect personal data about you is corrected/rectified
- receive a copy of your personal data (data portability), and
- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data

What gives us the right to process your personal data?

I will process your personal data based on your consent.

Based on an agreement with *Western Norway University of Applied Sciences*, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation.

Where can I find out more?

If you have questions about the project, or want to exercise your rights, contact:

- Western Norway University of Applied Sciences via
    - Student: Negar Safara Nosar (negarsafara@gmail.com, +4798044241)
    - Supervisors: Geoffrey Sean Gilpin (Geoffrey.Sean.Gilpin@hvl.no)
    - Data protection officer at HVL: Trine Anikken Larsen (Trine.Anikken.Larsen@hvl.no, 55587682)

- NSD – The Norwegian Centre for Research Data AS: (personverntjenester@nsd.no) or by telephone: +47 55 58 21 17.

Yours sincerely,
Negar Safara Nosar

Consent form

I have received and understood information about the project '*Hydrogen in the maritime sector in Western Norway: Evaluation of production and implementation in a value chain'* and have been given the opportunity to ask questions. I give consent:

- ☐ to participate in this interview
- ☐ for my voice to be recorded
- ☐ for the entire zoom meeting to be recorded (audio and video)
- ☐ for information about me/myself to be published anonymously in the written thesis.
- ☐ For the final thesis to be shared with the administration of the EU Climate Pact, in order to help them in future recruitment of the initiative.

I give consent for my personal data to be processed until the end date of the project, approx. 10/6/21

(Signed by participant, date)

8.3. Appendix 3

Theme	Interview questions	Notes
Introduction to my thesis	My name is Negar, I am a master student at HVL, where I study Climate Change Management. In my master thesis I looks at the hydrogen value chain in Norway particularly in Norwegian maritime sector. More specifically I seek to understand *what* parameters will lead to a sustainable transition to hydrogen technologies, and about the blue and green hydrogen status in Norway using technological innovation system assessment. Actually my survey is in progress, but based on what I have found by interviewing firms and companies involving in 3 hydrogen development projects in Western Norway, it seems like there are some arguments on the way that funds and governmental supports are allocating, I would be grateful if you share your knowledge and experience in this regard.	
Consent	You have already signed the formula I sent you, but I just want to make sure that it is okay with you, that • I record the interview? • I share the written thesis with the administration of NTRANS by the end of the project?	
Introduction to interviewee	First of all, can you please tell me about yourself and your position in the organization? • Could you please tell me about the Company? • What companies and firms are involved in your network? • Could you please tell me about the Project? • Does any of firms participating in project have prior experiences on other type of fuels?	
Motivation	• What was the initiating motivation for cooperating in this project? • What is the reason for focusing on hydrogen in maritime sectors?	
The Project	• What would be the role of this project in transition to hydrogen? • What are the challenges and benefits? • How can these issues be resolved?	

	• How does the location of energy park influence on development project? • Who are the potential users of the hydrogen produced?	
ITS elements	• What is the role of policy in establishment of hydrogen development projects? (Type and scale) - Does it differ considering the type of produce hydrogen or the scale of project? • How investment can influence the transition to hydrogen technologies? • How the standards and regulations have influence on your choice? • What is your view on the research programs direction relating to hydrogen development? - Which part of the value chain is a priority for technology development?	
Ending	How do you predict the situation in near future (for instance 10 years from now)? • How it would be possible to reach that point? • Any issue that I have not mentioned and you would like to add?	