Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Social and Educational Sciences
Department of Geography

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Green autonomous technology for maritime transport in Norway

A technological innovation system analysis

Master's thesis in Innovation, Entrepreneurship and Society
Supervisor: Markus Steen
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NTNU
Kunnskap for en bedre verden

Abstract

Our society is currently in the midst of several ongoing and major transitions, including the twin transitions of digitalization and sustainability. Such transitions involve far-reaching changes along several dimensions (e.g., technological, institutional, political, and socio-cultural). Sustainable transition studies aim to understand how changes in socio-technical systems lead to transformation due to societal and technological pressure. Applying the technological innovation system framework, one of two dominant perspectives in recent studies of sustainability transitions, this thesis is broadening the analytical focus of innovation systems to include changes in practices and institutional structures.

The formation of innovation systems is essential in the development and diffusion of new knowledge. This thesis applies the technological innovation system (TIS) framework to research the TIS of green autonomous technology for maritime transport in Norway. TIS structural components; actors, networks, and institutions have been identified, and key innovation-related processes have been assessed through an empirical mapping of seven functions: 1) Knowledge development and diffusion, 2) Entrepreneurial experimentation, 3) Market formation, 4) Influence on the direction of search, 5) Resource mobilization, 6) Legitimation and 7) Positive externalities. This allows for the systematic production of knowledge about the development, diffusion, and implementation of innovations within the technological field.

Maritime transport can be conceptualized as a socio-technical system, as transport fulfills a function in society. Green autonomous technology can be utilized to realize new and better transport systems in the maritime sector. The fact that world´s first zero-emission and autonomous container vessel, Yara Birkeland, is operating in Norwegian waters underbuilt this. However, a more substantial commitment from the government is requested, and more resources need to be allocated to projects featuring both green- and autonomous technology. Moreover, a standardized approval process for autonomous operations and significant investments in complementing infrastructure and competence will be essential for implementing green autonomous technology on a large scale. Social acceptance and trust in such a complex system will also be discussed, and uncertainties regarding acceptable risk levels and resource mobilization will be addressed. Furthermore, feasible segments for application will be identified.

Sammendrag

Samfunnet vårt står i dag ovenfor flere store omstillingsprosesser, derunder omstillingen til et mer digitalt og bærekraftig samfunn. Slike omstillingsprosesser involverer store endringer langs flere dimensjoner (f.eks. teknologiske, institusjonelle, politiske og sosiokulturelle). Studier som tar for seg bærekraftig omstilling, tar sikte på å forstå hvordan endring i sosiotekniske systemer bidrar til omstilling, som et resultat av et samfunnsmessig og teknologisk press. Ved å anvende rammeverket for teknologisk innovasjonssystem, et av to dominante perspektiver i nyere studier om bærekraftig omstilling, utvider denne oppgaven det analytiske fokuset til innovasjonssystemer, til å også analysere endring i praksis og institusjonelle strukturer.

Etableringen av nye innovasjonssystemer er essensielt for utvikling og spredning av ny kunnskap. Med utgangspunkt i det teoretiske rammeverket 'teknologisk innovasjons-system' tar denne oppgaven sikte på å analysere det teknologiske innovasjonssystemet rundt grønne autonome teknologier for maritim transport i Norge. Strukturelle komponenter; aktører, nettverk og institusjoner, er identifisert og nøkkel prosesser for innovasjon har blitt vurdert gjennom en empirisk kartlegging av sju funksjoner: 1) Utvikling og spredning av kunnskap, 2) Entreprenøriell virksomhet, 3) Markedsdannelse, 4) Påvirkning på søkeretning, 5) Mobilisering av ressurser, 6) Legitimitet og 7) Utvikling av eksterne effekter. En slik systematisk analyse gjøre det mulig å produserer kunnskap om utvikling, spredning og implementering av ny innovasjon innenfor forskningsfeltet.

Maritim transport utgjøre en funksjon i samfunnet og kan derfor forstås som et sosioteknisk system. Grønn autonom teknologi kan være et virkemiddel for å oppnå nye og bedre transport systemer i maritim sektor, og det faktum at verdens første null-utslipp og autonome containerskip, Yara Birkeland, er i operasjonell drift i norske farvann underbygger nettopp dette. Likevel er en større satsning fra regjeringen etterspurt, og mer ressurser må bevilges til prosjekter som involverer både grønn og autonom teknologi. I tillegg er en standardisert godkjenningsprosess for autonome operasjoner, samt investeringer i infrastruktur og kompetanse nødvendig for å muliggjøre implementeringen av grønne autonome løsninger i stor skala. Sosial aksept og tillit til et slikt kompleks system vil også bli diskutert, og usikkerhet knytt til akseptable risikonivå og mobilisering av ressurser vil bli adressert. I tillegg, vil egnede segment for implementering bli kartlagt.

Acknowledgment

Writing this paper has taught me so much about myself. Still, most importantly, I have understood the importance of understanding complex processes leading to changes to grasp how society will look 5-10 years from now.

First, I would like to express gratitude to my supervisor Markus Steen. Thank you for excellent guidance, encouraging conversations, and constructive criticism challenging me to search in new directions. You have been a great support throughout this process.

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Jenny M. Tomasgard
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Abbreviations

TIS	Technological Innovation Systems
MASS	Maritime Autonomous Surface Ships
NFAS	Norwegian Forum for Autonomous Ships
RCC	Remote Control Centre
NTNU	The Norwegian University of Science and Technology
NMA	Norwegian Maritime Authority
NCA	Norwegian Coastal Administration
NSA	Norwegian Shipowners Association
IMO	International Maritime Organization
NIC	Norwegian Innovation Cluster
NTP	National Transport Plan

1 Introduction

This thesis aims to research sustainability transitions in the socio-technical system of maritime transport in the geographical context of Norway. Applying the technological innovation system (TIS) framework, the thesis determines system performance on a functional level. Seven functions are assessed, and processes leading to technological development within the TIS of green autonomous technology for maritime transport are identified. This provides actors with valuable information they can act on to make informed decisions on where to put pressure to accelerate technological developments further.

1.1 Introduction to the field

Maritime transport can be conceptualized as a socio-technical system in which various elements are interlinked, depending on each other, and together provide a service to the society (Bergek et al., 2021; Markard et al., 2012a). Maritime transport fulfills a function in the society (Geels, 2004), but it also accounts for approximately 2,9 percent of carbon dioxide emissions globally (IMO, 2020). Therefore, new and better transport systems are needed, and green autonomous technology can be a means of this transition.

Norway is considered a leader in developing low- and zero-emission carbon technologies in maritime shipping (Bergek et al., 2021). With the development of the world's first zero-emission autonomous container ship, Yara Birkeland, which was set in operation in Norwegian waters in April 2022 (Stensvold, 2022), Norway is also positioning itself at the forefront in the development of autonomous technology for maritime shipping. With that said, autonomy is first and foremost a tool that should be implemented in combination with green technologies to generate the most. Therefore, this research study aims to understand the processes taking place within the TIS of green autonomous technology for maritime transport and how these can lead to changes in society.

Green technology can be defined as a technology intended to mitigate or reverse the effect of human activity on the environment (Stuchtey et al., 2020). In the shipping industry, green technology is often associated with alternative fuels (e.g., ammonia, hydrogen, LNG) and the electrification of ships (Mäkitie et al., 2022); however, green technology also includes technological advancements in specific components. Autonomous ships can be defined as "a ship where the computerized control system has the possibility to sense the environment and make its own decisions as to how the ship should be maneuvered in a given situation" (Rødseth & Nordahl, 2018). Autonomous vessels, depending on the degree of autonomy, can conduct a situation analysis and make decisions on their own. Implementing green autonomous technology in maritime transport systems has apparent benefits, but it also has some challenges.

1.2 Significance of the study

In recent years, systems of innovation studies have shifted the focus toward specific technologies, and recent TIS studies have developed a much stronger emphasis on specific technologies (Hekkert et al., 2007). Sustainable and radical innovations have been of particular interest for their potential to challenge established socio-technical systems (Markard et al., 2012b). In other words, the analytical interest has in recent years shifted from “technological innovation contributing to the economic growth of countries” to “new technologies as nuclei for fundamental socio-technical transitions” (Markard et al., 2012b). This research adds to the analytical interest in the system of innovation studies, focusing on green autonomous technology for specific applications in maritime transport systems.

Our society is today in the midst of several ongoing and major transitions. However, the maritime sector is characterized by slow-moving processes due to complex regulatory frameworks, long lifecycles, and small financial margins. Such factors give stability to already established socio-technical systems and create resistance to change, as firms tend to stick to their core technologies as long as possible (Hassink, 2010). On the other side, challenges in terms of climate change are putting pressure on sectors like energy and transport to transition. Such transitions involve far-reaching changes along several dimensions (e.g., technological, institutional, political, and socio-cultural) (Markard et al., 2012a).

The TIS of green autonomous technology is today characterized by R&D activities, experimentation, piloting, and processes of legitimation. Several steps have been taken to green the fleet (Steen et al., 2019), and autonomy is gaining momentum for its potential to improve transport systems and reduce emission (Ministry of Transport, 2016-2017). An increased focus on the ocean globally (Stuchtey et al., 2020) and Norway’s strategic goal of becoming a world-leading ocean nation (Ministry of Trade, 2021a) are also factors driving the development forwards. The fact that the world´s first zero-emission and autonomous container vessel was set in operation on April 21st this year (Stensvold, 2022) emphasizes the interest in using the technology as a means in the transition.

Sustainable transition studies aim to understand how changes in socio-technical systems lead to transformation, and digitalization and a demand for more sustainable solutions hold the potential to create disruptive changes to maritime transport. Yet, it can be argued that maritime transport as an empirical field has been neglected within sustainability transition research (Bergek et al., 2021; Steen et al., 2019). This thesis aims to contribute to filling this research gap as it is the first of its kind within the empirical field of interest.

> “In the maritime sector, pollution reduction targets and export opportunities have led to a rapid development of, e.g., battery-electric and hydrogen innovations, especially in the ferry segment, while especially autonomous vessels are seen as a future technology enabling more cost-efficient operations and new modes of transport” (Mäkitie et al., 2020).

1.3 Defining the research question

New technological development and stricter environmental requirements both nationally and internationally are forcing industries to change, and maritime transport is no exception. Applying the TIS framework, this thesis research green autonomous technology for maritime transport as a TIS in which the structural components of an innovation system; actors, networks, and institutions (Carlsson & Stankiewicz, 1991) are identified and seven functions are assessed (Bergek, Jacobsson, Carlsson, et al., 2008).

Analyzing system performance on a functional level allows for a better understanding of the processes taking place within the TIS, and how these can lead to changes in the society. Additionally, feasible segments for application, system-building activities, and potential bottlenecks can be identified, which provides actors with valuable information to act on.

Worth noticing is that functions within a TIS are highly dependent on each other, and processes taking place within one function can influence the strength of another. Chapter three and chapter five will discuss the functional patterns of the TIS more in-depth.

What the thesis aims to investigate is:

> *What can the TIS of green autonomous technology teach us about the technology and the benefits of implementing it in maritime transport systems?*

The following sub-questions have then been outlined:

1. *What processes can be observed within the TIS today?*
2. *What segments are considered most feasible for application?*
3. *Which system-building activities can strengthen the TIS further?*
4. *Can any bottlenecks be identified? If so, what is being done to tackle them?*

1.4 Thesis outline

The remainder of this thesis is structured in six parts as follows. Chapter two presents the industry background, and the theoretical framework applied. Chapter three presents relevant theories and concepts and elaborates further on the theoretical perspective of Technological Innovation Systems (TIS) and how the framework will be used in the analysis. Chapter four outlines the research methodology and aims to describe and discuss the relevance of the selected method and the quality of the research design. Chapter five presents the functional analysis and assesses the seven functions of interest in the TIS framework. Chapter six then discusses critical findings before the final chapter concludes by summarizing the main takeaways, bringing the analysis to an end.

1.5 Personal motivation

Two personal experiences sparked my interest in green autonomous technology in particular. In the fall of 2021, I worked with a cluster in Trondheim with arena status in the national cluster program, Norway Innovation Cluster (NIC). After the semester, I was asked to continue working for them as an intern throughout the summer. I took the opportunity and used it to grow my interest and knowledge in the field. While working there, I applied for an internship through Innovation Norway as part of my master´s program to work at the Kingdom of Norway pavilion during the World Exposition. I got the position and spent approximately four months in Dubai, UAE, showcasing Norway's newest innovative solutions and technology within ocean industries to an international audience. The main goal of Norway's participation was to strengthen Norway's position as a world-leading ocean nation and a pioneer in sustainable ocean solutions (Expo2020Dubai, 2022). This allowed me to understand the potential new and sustainable technology hold in transforming industries, and I am interested in building my competence in this field further.

2 Maritime Transport

Norway has the second-longest coastline in the world and a strong maritime cluster with a unique combination of active owners looking for new and profitable solutions and skilled seafarers with practical experience (Ministry of Trade, 2021a). With that said, stricter regulations on efficiency, environmental impact, and fast technological development are changing the framework conditions for businesses and industries (Mäkitie et al., 2022). Shipping companies are increasingly required to comply with new ESG (environmental, social, and governance) related standards and regulations, changing the landscape of established sectors (Haugland et al., 2022). At the same time, the COVID-19 pandemic, plummeting oil prices, and the ongoing war in Ukraine are affecting the innovative capacity of industries negatively, as it can slow down, e.g. the uptake of radically new technologies. This underbuilds the relevance of this study and the importance of understanding how complex processes such as new technological developments creates changes in society.

2.1 Industry background

Norway´s maritime cluster has been active in developing environmental innovations (Bach et al., 2020), and maritime activities have over the years resulted in a highly skilled and educated workforce in maritime sectors (Ministry of Trade, 2021a). Norway is also a major ship-owning country and is among the global leaders in maritime technology (Kongsberg, 2022; Tenold, 2019). Today, the Norwegian maritime cluster hold a complete value chain from shipbuilding to classification and shipping operations (Menon Economics, 2022).

Several white papers, strategies, and reports have been published to further develop the ocean industries and strengthen ocean management. The first comprehensive strategy that looked at ocean industries in context was "New Growth, Proud History," published in 2017 (Ministry of Trade & Energy, 2017). A new strategy, "Blue Opportunities," was then published in 2019 (Ministry of Trade, 2019). Both these strategies focused on how to use the ocean in a responsible manner. Today, "Blue Ocean, Green Future" is the government's updated ocean strategy which sheds light on recent investment in ocean industries and the importance of a sustainable transition in maritime sectors for the welfare of the Norwegian society as a whole (Ministry of Trade, 2021a).

Congestion, CO2 emissions, and air pollution (NOx) are some challenges the transport sector is facing (Geels, 2004), challenges that can be increasingly curbed via regulations, alternative fuels, and a more flexible transportation system (Mäkitie et al., 2022). In fact, emissions have to be curbed as the NSA has pledged to achieve climate neutrality by 2050 (NSA, 2020). On an industry level, the more recent report Green Maritime 2022 stresses the need for a green and digital transition in maritime industries to reach the targets set out in the Paris Agreement (Haugland et al., 2022). The basis for the report was a call-out from the Norwegian Shipowners Association (NSA), requesting a revision of the targets and ambitions set out in the report Green Maritime from 2019 (Helseth et al., 2019). New targets were set, and an action plan on how to reach them was presented to ”build knowledge in how to achieve a successful green transition in the maritime sector through significant emission reduction, and a solid contribution to reach net-zero by 2050” (Haugland et al., 2022).

It is through experimentation and the formation of markets, that expectations towards technology can be formed (Geels & Raven, 2006), and radical innovation can eventually compete with established technologies (Tsouri et al., 2022). Over the last decade, several milestones have been reached both within the TIS of green technologies and within the TIS of autonomous technologies. Norwegian ship-owners were major frontrunners in adopting LNG propulsion systems during the first decade of the 2000s, and in 2021 about 40% of all the world's battery-electric vessels were operating in Norway (DNV, 2021; Mäkitie et al., 2022). Among the proposed alternative fuels for shipping hydrogen, liquified natural gas (LNG), various types of biodiesel, liquefied biogas (LBG, biomethane), ammonia, and methanol have been presented as the most promising solutions (Mäkitie et al., 2022) In terms of autonomy, are the first zero-emission and autonomous vessel operating in Norwegian water (Stensvold, 2022), several projects are under development and four designated test areas for autonomous operations have been granted approved (INAS, 2022; Moderne Transport, 2021). Adding to that, different levels of autonomy have been determined (Rødseth et al. 2022), and actors are working closely with the EU to develop a standardized approval process for autonomous operations (IMO, 2018).

2.2 A sustainable transition

Norway aims to be climate-natural by 2030 and a low-emission society by 2050 (Haugland et al., 2022; Ministry of Climate, 2016-2017). The Norwegian government is also committed to halving emissions from domestic shipping and fisheries by 2030 compared to 2005 emissions (Ministry of Trade, 2021a). The Norwegian government have placed great emphasis on the importance of working together to solve climate challenges, and frameworks for international climate negotiations, such as the UN Climate Convention of 1992, the Kyoto Protocol from 1997, and the Paris Agreement of 2015, outline strategies and targets on a national and international level (Menon Economics, 2022; Ministry of Trade, 2021a; Ministry of Trade & Energy, 2017). Sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987), and a sustainable transition of the maritime sector provides new opportunities for restructuring, innovation, and growth in existing systems (Ministry of Trade, 2021b).

Nationally, the Norwegian Climate Change Act paves the way for significant emission reductions, and reports such as "Green Maritime 2022", "National Transport Plan 2022-2033," and "Zero Emission in 2050" provide roadmaps and guidance on how to utilize new technology and knowledge in the transition to a more sustainable maritime sector (Haugland et al., 2022; Ministry of Transport, 2020-2021; NSA, 2020). A green shift in the shipping industry and transport was two of the areas given priority in the government strategy "Climate strategy for 2030" to achieve the targets set out in the Paris agreement together with the EU (Ministry of Climate, 2016-2017). The report also reveals that the government, through public demands and commitments through Enova, has secured the implementation of several new zero- and low-emission ferries along the coast (Ministry of Climate, 2016-2017). The adoption of alternative fuels plays a crucial role in decarbonizing the shipping sector (Bergek et al., 2021; Mäkitie et al., 2022). With that said, the potential of autonomous technology has also been addressed by the Norwegian Government in government papers such as the National Transport Plan (NTP) 2022-2033, which is the government´s roadmap to achieve efficient, environmentally friendly, and safe transportation systems by 2050 (Ministry of Transport, 2020-2021).

Favorable societal and economic conditions can also be means for a breakthrough of radical innovations (Köhler et al., 2019). The twin transitions of digitalization and sustainability are two such favorable socio-economic conditions driving the development of green autonomous technology for maritime transport in Norway.

2.3 New technological developments

New technological developments have paved the way for innovation and development in the shipping sector. More data is being exchanged, and real-time data can be collected, allowing for optimization of shipping operations in regards to, e.g., navigation and fuel consumption (Menon Economics, 2022). Digitalization of transportation systems holds the potential to improve traffic flows and reduce emissions (Mayer et al., 2019; Ministry of Climate, 2016-2017). However, digitalization is first and foremost a tool and a result of a fast technological development (Geels, 2002; Haugland et al., 2022; Mäkitie et al., 2020). In the maritime sector, attention to digital technologies has primarily been focused on automation, sensor, and performance modeling, which enable the development of concepts such as autonomous vessels and digital twins (Mäkitie et al., 2020).

Autonomous technology has received increased interest over the last decade for its potential to optimize transport routes, reduce risk and cost, and potentially challenge land-based transportation through new and sustainable modes of transport. Autonomous vessels, or Maritime Autonomous Surface Ships (MASS), can be referred to as "a ship which, to a varying degree, can operate independently of human interaction" (IMO, 2018). Digital technology plays a vital role in the development of autonomous technology. However, like digitalization, autonomy is a tool that relies heavily on a skilled and educated workforce and significant investments in infrastructure to generate value (Mayer et al., 2019). Furthermore, several challenges, e.g., public acceptance, acceptable risk levels, and a lack of a standardized approval process, can be observed (NFAS, 2022). These challenges need to be dealt with before green autonomous technology can be implemented in maritime transport systems on a large scale.

The international maritime organization (IMO) included the concept of MASS on its agenda in 2017 and is today actively involved in the development of a regulatory framework for autonomous ships (IMO, 2018). A regulatory scoping exercise was finalized in 2021 to assess the next steps for regulating MASS (Maritime Safety Committee, 2021). Levels of autonomy can be defined based on the combination of automation and human control that applies to the vessels. Table 1 provides an overview of these levels and a brief description. Addressing different levels of autonomy is relevant as the relationship between autonomy and crew presence often gets confused when talking about autonomous vessels (Rødseth et al., 2022). Conclusions can quickly be drawn that "autonomous" means full autonomy (i.e., vessels operating without human control), but this is not the case. Ships can build their autonomous capabilities through different combinations of crew attendance both on the vessel and from Remote Control Centers (RCC), which is seen in projects today. For some segments, It can even be argued that full autonomy is unrealistic that will ever be achieved.

With this in mind, Rødseth and Nordahl (2018) argue that the main reason for the great interest in autonomous ships is that they can be used to develop entirely new transport systems. More competitive, safer, and greener shipping are reasons why autonomous ships should be part of future maritime transport systems (Rødseth & Nordahl, 2018).

Table 1: The most relevant combination of automation and human control today, presented by Rødseth, Wennersberg and Nordahl (2022) in the paper "Levels of autonomy for ships."

	Levels of Autonomy	**Brief description**
1	Direct control (DC)	This is the situation on ships today where the crew has full control of the ship and uses relatively simple automation and decision support functions
2	Automatic operation (AO)	Examples of this could be dynamic positioning, automatic berthing, or automatic crossings where automation performs operations under continuous supervision
3	Remote supervision (RS)	A ship with conventional crew, and with DC or AO autonomy level onboard, is continuously supervised from shore, e.g. for increased safety.
4	Remote control (RC)	In this case the ship would be remotely controlled from shore, either all the time or, e.g. during night time. This normally uses the AO autonomy class, as OE is more work intensive for the RCC operators, and one will want to avoid this, if possible.
5	Periodically unattended (PU)	The ship can steer itself automatically for extended periods, e.g. in open waters and calm weather. Crew is available onboard to handle more complex situations, but can be away from the controls and, possibly at sleep during nighttime.
6	Constrained autonomous (CA)	Uncrewed operation with constrained autonomy onboard but with operators in RCC that can handle more complex situations. This corresponds to PU onboard
7	Fully autonomous (FA)	The ship handles all foreseeable situations by itself and there is no crew neither on ship nor in RCC. This is not very realistic today, except in very simple cases
Additional explanation of abbreviations for the purpose of reading this table: OE= Operate exclusive - Limited automation, operator must be always present. RCC= Remote control center		

3 Theory

According to Markard and Truffer (2008), the technological innovation system (TIS) framework is one of two dominant perspectives in recent studies of sustainability transitions. This thesis research the TIS of green autonomous technology for maritime transport in the geographical context of Norway and aims to broaden the analytical focus of innovation systems to include changes in user practices and institutional structures (Geels, 2004; Markard et al., 2012a). In the following sections, theories of structural change will be presented before the concept of innovation systems, and the theoretical perspective of TIS will be further explained. Cluster theory ends the chapter.

3.1 Theories of structural change

Innovation can be defined as "the introduction of new or novel developments in goods or services, processes, technologies and organizations" (Pike et al. 2017(110)). As mentioned, maritime transport can be conceptualized as a socio-technical system, and fulfillment of societal functions is central to driving innovation processes (Geels, 2004). The capacity of a nation to generate advanced technology, information, and, ultimately, knowledge is regarded as the single most influential force driving the secular process of economic growth (Porter, 1998). On the other hand, innovation is one of the most challenging processes to manage. Because of a certain level of stability in established socio-technical systems, a certain resistance to change can evolve (Geels, 2004).

The long-wave theory of innovation focuses on internal changes within regions to explain local and regional development, and Joseph Schumpeter´s theory of long waves provides the basis (Schumpeter, 1994). Transitions between long waves occur through a process of what Schumpeter called "creative destruction," and the creation of a new wave represents the beginning of a more advanced techno-economic paradigm (Pike et al. 2017 (97)).

> "Downswings cause a "bunching" of innovation and stimulate entrepreneurial activity to lay the foundation of structural change and a successive "techno-economic" paradigm" (Sternberg, 1996).

In other words, the long wave theory presents development by visualizing how innovations and entrepreneurial activities have lifted the world economy out of periods of recession or depression and into periods of improvement and prosperity. Entrepreneurial activities within the TIS of green autonomous technology can be understood as a response to a downturn in established systems (e.g., oil and gas), and actors looking for opportunities in new and, in this case, more sustainable fields.

Another way of understanding structural change is by looking at significant industrial shifts. The first industrial revolution moved our economy from agriculture to industry and introduced innovations such as steam and water power and more organized transportation routes. Since then, the second and third industrial revolutions have brought significant breakthroughs in electricity, communication, new forms of power generation, and the development of digital systems enabling new ways of generating, processing, and sharing information (Davis, 2016). The fourth industrial revolution, also known as Industry 4.0, marked the shift to a knowledge-based and digital economy and represented entirely new ways technology became embedded within societies (Davis, 2016). These transformative technological changes resulting from innovation and new customer demands have paved the way for significant industrial and economic development.

3.2 Innovation systems

In the most general sense, an innovation system is a system in which elements are joined together and connected by a web of relationships (Bergek, Hekkert, et al., 2008). Systems of innovation can be defined on several levels (Geels, 2004); national innovation systems (Lundvall, 2007), regional innovation systems (Asheim & Gertler, 2009; Cooke et al., 1997), sectoral innovation systems (Malerba, 2002) and technological innovation systems (Bergek et al., 2015). This thesis researches innovation systems on a technological level.

The goal of an innovation system is to develop, apply, and diffuse new technological knowledge (Hekkert et al., 2007). An important aspect in this regard is the difference between "catching up" learning based on incremental innovations and knowledge creation as input for radical innovations (Asheim & Coenen, 2005). Entrepreneurial activities leading to knowledge development and diffusion and knowledge creation as input for radical innovations rather than "catching up" are of substantial interest in this research study.

Norway has a coordinated market economy with a strong emphasis on collaboration between employees, unions, and government (tripartite cooperation) and between university, industry, and government (the triple helix model) (Ministry of Trade, 2021a; Strand & Leydesdorff, 2013). This highlights a competitive advantage in producing systemic innovations (Strand & Leydesdorff, 2013). Adding to that, development can be explained as the "enhancement of the ability of actors in localities and regions to produce, absorb and utilizes innovations and knowledge through processes of learning and creativity" (Pike et al. 2017(110)). In recent decades, the Norwegian government has promoted clusters and regional innovation system policies to enhance the innovative capacity at the local and regional levels (Asheim & Coenen, 2005; Ministry of Trade, 2019).

The public sector can also take a proactive role in strengthening innovation systems, as new funding and support schemes can be developed, investments in infrastructure can be made, and incentives put in place as means to drive innovation and development of new and greener technologies (Innovation Norway, 2022; RCN, 2022b; SIVA, 2022). When innovation systems emerge, they have to compete with established systems for public funding and support. This creates resistance from parties with vested interest in efforts to defend existing TISs and the institutional framework associated with them (Bergek, Hekkert, et al., 2008). With that said, public funding and support schemes should support technologies that meet demand in the society and more resources should be allocated to specific technologies in which opportunities for innovation and development can be observed, and lead to change in the society. Scholars in the sociology of technology and evolutionary economics have highlighted the importance of niches, a key concept in transition studies, as the locus of radical innovations (Geels, 2004; Markard et al., 2012a).

> "The emergence of a new innovation system and changes in existing innovation systems co-evolve with the process of technological change" (Hekkert et al., 2007).

Policy interventions that utilize property-based approaches (e.g., business incubators, business gardens, and research and technology parks) are another way of developing systems of innovation as it facilitates a strong regional infrastructure for innovation and enables actors to work together and experiment with new technology (SIVA, 2022).

3.3 Technological innovation systems (TIS)

Technological innovation systems is a theoretical perspective introduced in 1991 as "a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or a set of infrastructures and involved in the generation, diffusion and utilization of technology" (Carlsson & Stankiewicz, 1991). The TIS framework understands innovation system dynamics beyond structural components; actors, networks, and institutions, to include a set of innovation-related processes (Bergek, Jacobsson, Carlsson, et al., 2008). Mapping functional patterns of a TIS allows for a better understanding of system performance, and new knowledge can be developed.

> "The central features of technological systems are economic competence (the ability to develop and exploit new business opportunities), clustering of resources, and institutional infrastructure" (Carlsson & Stankiewicz, 1991).

A function can be defined as "a process that influences an innovation system´s ability to reach its intended goal through development, diffusion, and implementation of innovations within a technological field" (Bergek et al., 2005). The TIS framework is particularly useful when analyzing the dynamics and activities taking place in innovation systems of emerging technologies, and a recent series of studies have addressed the relevance of applying the framework when researching technology leading to sustainable transitions (Bach et al., 2020; Hekkert et al., 2007; Jacobsson & Bergek, 2004; Markard et al., 2012a). Seven key innovation-related processes, referred to as "functions" from now on, have been identified: 1) Knowledge development and diffusion, 2) Entrepreneurial experimentation, 3) Market formation, 4) Influence on the direction of search, 5) Resource mobilization, 6) Legitimation, and 7) Positive externalities (Bergek, Jacobsson, Carlsson, et al., 2008). By assessing the strength of each function through a functional analysis, system-building activities can be identified, and various inducement and blocking mechanisms can be observed. The characteristics of the seven functions are further described in chapter 3.3.2.

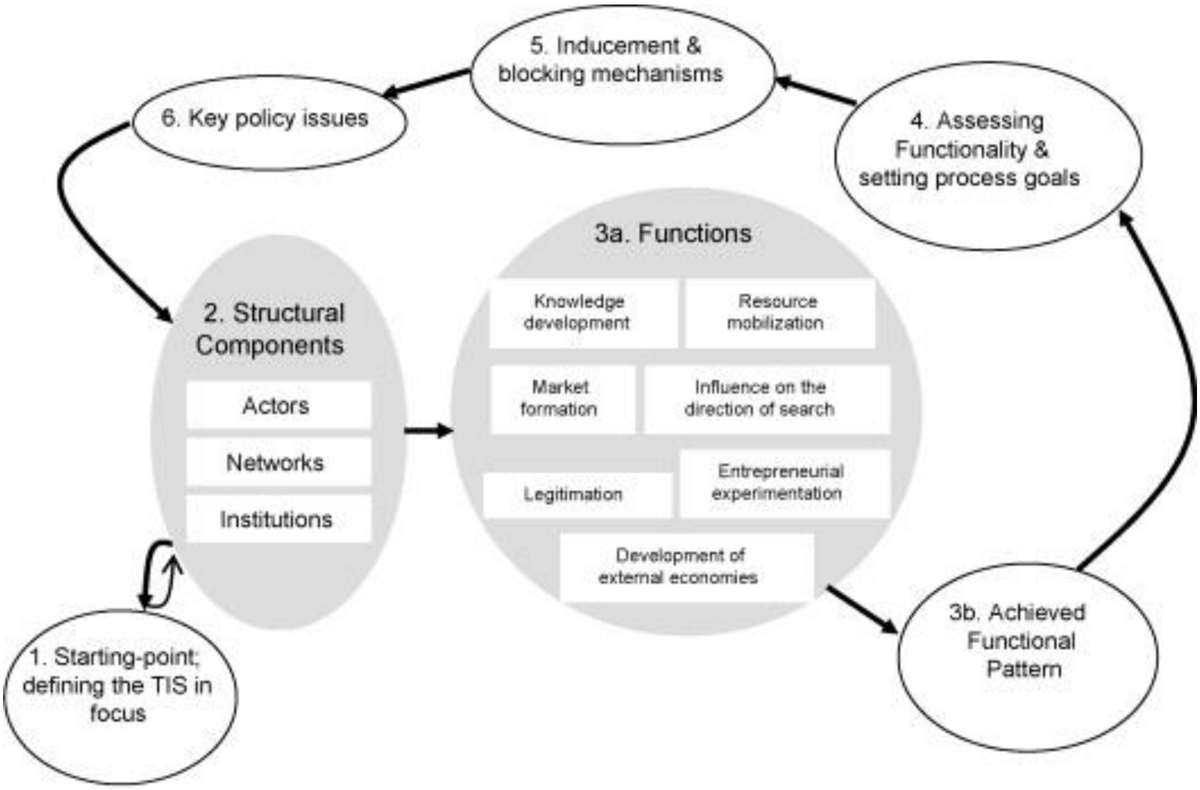


Figure 1: The Scheme of analysis (adapted from Otlander and Perez Vico, 2005)

The TIS approach derives from the idea that technological innovations lie at the core of transition processes (Coenen, 2010). The fact that this analysis focuses on sustainable innovations in transport systems adds a socio-technical dimension to it. Structural components and functional patterns will be further addressed in the next section.

3.3.1 TIS structural components

The structural components of a technological innovation system are as mentioned: actors, networks, and institutions. The arrangement and character of these structures make a particular TIS unique (Carlsson & Stankiewicz, 1991). "The formation of a new TIS involves three structural processes: entry of firm and other organizations, formation of networks and institutional alignment" (Bergek, Hekkert, et al., 2008). Essential for innovation systems around emerging technologies (e.g., green autonomous technologies) are structural components' ability to diffuse knowledge and identify system weaknesses (Bergek, Jacobsson, Carlsson, et al., 2008). When a TIS reaches a certain level of structural components, it will eventually be self-sustained; however, until then, actors should expect to meet obstacles that are capital intensive without an immediate return on investment.

Actors.

Actors and their decision-making create change, and knowledge recombination can potentially reshape system dynamics (Tsouri et al., 2022). Actors span the entire value chain of industries to include societal groups, public authorities, and research and development organizations, whom all play a role in shaping system dynamics (Geels, 2004). Characteristics of emerging technological fields are new actors entering the TIS, adding value and improving the system performance through diversifying the entrepreneurial activities resulting in knowledge being developed (Hekkert et al., 2007).

Networks.

Networks can be significant drivers of innovation and development. The essential function of networks is the exchange of information (Carlsson & Stankiewicz, 1991). Networks work as bridging organizations in places where knowledge- and technology development takes place and can be both formal (e.g., clusters in which members have contracted agreements) and informal (e.g., conferences or interaction between actors leading to tacit learning) (Bergek et al., 2005). As a result of network activities, knowledge development and diffusion of technologies can reshape the dynamics and pace of evolution in a field.

Institutions.

Institutions specify the "rules of the game" and, like networks, can also institutions be formal or informal (Geels, 2004; Malerba, 2002). Institutions promote stable patterns of social interaction/transactions necessary for the performance of vital societal functions (Carlsson & Stankiewicz, 1991), and can stimulate and regulate innovation processes. From sustainability research perspectives, technological transitions and institutional change are closely related and necessary processes for new TIS to gain ground (Markard et al., 2012a; Truffer & Coenen, 2012).

3.3.2 Functional components

When new technologies emerge, innovation systems are formed around the technology, which can cause changes in existing systems. The TIS of green autonomous technology for maritime transport is still in a formative phase. Applying the TIS framework in functional terms (Bergek, Hekkert, et al., 2008), TIS this thesis aims to contribute with valuable insight into the development, diffusion, and use of the technology.

1. Knowledge development and diffusion

The knowledge development and diffusion function are concerned with the breadth and depth of the knowledge base of the TIS and how well that knowledge is diffused and combined within a system. The concept of learning is at the core of the innovation system approach (Bergek, Hekkert, et al., 2008). For learning to occur at a system level, one of the prerequisites is knowledge diffusion: "the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning" (Lundvall, 1992).

2. Entrepreneurial experimentation

The entrepreneurial experimentation function refers to the processes of exploring and exploiting business opportunities based on new technologies and applications (Coenen, 2010). Through experimentations, a social learning process will unfold in which some technologies and firms will fail while others succeed (Bergek, Hekkert, et al., 2008). Additionally, entrepreneurial experimentation allows for knowledge to be collected on the functioning of the technology under different circumstances, and the reaction of consumers, government, competition, and suppliers can be observed.

3. Market formation

The market formation function refers to how innovation systems gain ground and disrupt the status quo of existing systems (Coenen, 2010). For radical innovations, markets may not exist yet. Existing markets with vested interest and stable political and social institutions can feel threatened and try to slow down the development of innovation systems (Truffer & Coenen, 2012). Niche markets for special applications are one way of shielding new technology from established environments (Schot et al., 1994). It also allows actors to experience and learn about the technology so that it can overcome its "liability of newness" without being marginalized (Bergek, Hekkert, et al., 2008).

4. Influence on the direction of search.

The influence on the direction of the search function refers to mechanisms that influence the selection or rejection of a particular technology by actors (Coenen, 2010). Such mechanisms, e.g., competing technologies, stricter regulations, new markets, or business models, influence actors' interpretation of entrepreneurial opportunities and willingness to invest in distinct technologies. These mechanisms are not only shaped by markets and governments but also by the interpretation of opportunities by entrepreneurial actors (Shane et al., 2003).

5. Resource mobilization

The resource mobilization function refers to the mobilization and allocation of resources needed to facilitate the various processes within an innovation system (Coenen, 2010). According to Bergek, Hekkert, et al. (2008) are, human capital (e.g., competence development), financial capital (e.g., policy support programs), and complementary assets (e.g., infrastructures) seen as basic inputs to all the activates within innovation systems.

6. Legitimacy

Zimmerman and Zeitz (2002) refer to legitimacy as a way to overcome the liability of newness and access resources needed to survive and grow. Legitimation can be seen as a prerequisite for forming new industries as it counteracts resistance to change (Coenen, 2010). However, when a new technology emerges, it often relates to or competes with established TISs. The resistance to change that can evolve can slow down processes of legitimation in efforts to defend established systems (Bergek, Hekkert, et al., 2008).

7. Positive externalities

The development of positive externalities indicates system dynamics on a functional level and refers to outcomes of investments that are hard to predict at the time of investment (Bergek, Hekkert, et al., 2008). The strengthening of a function in a specific TIS may stimulate the development of positive externalities in another TIS, leading to system growth both within emerging and established TISs (Bergek, Jacobsson, & Sandén, 2008). Porter (1998) underlines the central role of positive externalities in forming clusters, an influential attribute in developing green autonomous technologies.

Chapter 5.3 discuss functions further and aims to identify functional patterns.

3.4 Cluster theory

According to Porter (1998) cluster can be defined as "a geographical proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and externalities." Clusters are often geographically anchored and bring companies together in strategic links where knowledge transfer between the actors creates competitive advantages (Fitjar et al., 2016). Norway has a strong maritime cluster, but even more influential are small specialized clusters that connect actors and facilitate knowledge development and tacit learning.

In the early 2000s, the national cluster program, Norway Innovation Cluster (NIC), was established to facilitate and strengthen innovation processes in the country (Innovation Norway, 2019).”Through collaboration, the clusters contribute to increased productivity and innovation and digitization in businesses all over Norway” (Ministry of Trade & Energy, 2017). In other words, it allows experiences and knowledge to be gained and companies to strengthen their innovative capacity and contribute to structural adjustment through more innovation and increased productivity. Possible downsides of clustering can be situations of lock-ins which means that information will circulate within the cluster and prevent the acquisition of new knowledge (Boschma, 2005). In general, lock-in emphasizes continuity and stability rather than change (Hassink, 2010) and can be observed within established systems with strong institutional ties.

Porter (1998) contributed with another influential concept relevant to cluster theory: the economics of competitive advantage. The aim was to explain the role and dynamics of the geographical concentration or “clustering” of industries within national economies and their contribution to productivity growth and trading competitiveness (Porter, 1998). Firms’ close spatial and physical proximity can increase tacit learning, knowledge sharing, and other productive relations that collectively improve the competitiveness of participant business (Gertler, 2003). The ability of clusters to create a competitive advantage and utilize the knowledge that exists within and outside the cluster depends on the cluster’s absorptive capacity. Cluster absorptive capacity refers to the ability of clusters to absorb, diffuse and creatively exploit extra-cluster knowledge (Giuliani, 2005). The process of knowledge development and diffusion of technology, e.g., knowledge spillover and tacit learning in clusters, is further discussed in the empirical analysis.

3.5 Summary and key concepts

To summarize chapter three, the technological innovation system (TIS) framework is said to be one of two dominant perspectives in recent studies of sustainability transitions (Truffer & Coenen, 2012). The analytical focus of innovation systems has been broadened to include changes in user practices and institutional change (Bergek, Hekkert, et al., 2008), and theories of structural change have explained economic growth and prosperity through innovation cycles and significant industrial shifts leading up until today (Truffer & Coenen, 2012). The recent shift to a knowledge-based and digital economy has presented entirely new ways of working, and industries are forced to adapt to stay competitive.

Even though innovation is one of the most challenging processes to manage, an analysis of such systems can provide valuable information for actors to act. This research study analysis systems of innovations on a technological level. TIS structural components of a TIS; actors, networks, and institutions (Carlsson & Stankiewicz, 1991), are identified, and an assessment of functional dynamics of the TIS will be conducted through an empirical mapping of seven functions (Bergek, Jacobsson, Carlsson, et al., 2008). In addition, cluster theory has been presented as various networks are an essential attribute in the knowledge development and diffusion within the TIS. A strong emphasis is placed on collaboration.

4 Research methodology

This chapter outlines the research methodology applied and aims to describe and discuss the relevance of the selected method in the context of this thesis. First, the research design and its appropriateness will be addressed. Secondly, the data collection methods will be presented, followed by the analysis method. The quality of the research design is then discussed before a presentation of possible limitations is given. The chapter ends with a presentation of the ethical considerations of the analysis.

The thesis is linked to the SINTEF led research center INTRANSIT and is submitted and approved by the Norwegian Centre for Research Data (NSD). The geographical delimitation of the research is national, focusing on the TIS of green autonomous technology for maritime transport systems in Norway.

4.1 Research design

This research study is qualitative and builds on the theoretical perspective of TIS complemented by cluster theory to understand better how relations between TIS structural components influence the TIS and how they contribute to knowledge development and diffusion of the technology. The theoretical perspective of TIS is a relevant research methodology for sustainability transitions studies and one of two frameworks for analyzing prevailing socio-technical structures (Truffer & Coenen, 2012). Applying the TIS framework gives validity and reliability to the analysis, and the collection of data is also thorough and systematic. However, some weaknesses of the selected research method are observed.

4.1.1 Study approach

When choosing a research method, I first established an idea of the field of research. A qualitative research study was chosen because the intended purpose of the analysis is to produce new knowledge in the field of research and give policy recommendations on where actions are needed based on an assessment of processes taking place within the TIS today. Researching the potential of green autonomous technology for maritime transport systems, it was natural to look at sustainability transition research studies. Transport can be conceptualized as a socio-technical system; the TIS approach, therefore, stood out as it is one of two frameworks for analyzing prevailing socio-technical structures (Truffer & Coenen, 2012). The TIS framework provides a scheme for analyzing TIS structural components (actors, networks, and institutions) and functional dynamics within a TIS (Bergek, Jacobsson, Carlsson, et al., 2008) and is, therefore, well-suited for the analysis.

With that said, a qualitative study gives little room for duplication when working with emerging fields, considering the changing environment. This presents a weakness of the chosen approach. Additionally, when aiming to develop new knowledge, it is essential to be aware of various perceptions of reality and the degree of objectivity in collecting data (Presskorn-Thygesen, 2012). The TIS approach is criticized for personal involvement in collecting and processing primary and secondary data, as it can affect the subjectiveness of the interpretation and analysis (Bryman, 2012). With this in mind, I, therefore, tried to stay as objective as possible when handling data.

The following section provides an overview of how the interviews were conducted and how primary and secondary data were prepared to answer the paper's research question.

4.2 Data collection

The research study includes primary and secondary data collected through three main methods of data collection for qualitative studies: text analysis, interview studies, and observation studies (Skilbrei & Østbø, 2021). The primary data were collected through 10 semi-structured interviews. Informants selected for the semi-structured interviews represent clusters, industry forums, companies, maritime authorities, and public funding and support institutions. In February, March, and April, the initial interviews took place, with clarifications and citation approvals conducted in April and May. Due to travel and meeting restrictions caused by the COVID-19 pandemic, the interviews were conducted over Microsoft Teams' digital platform. Secondary data collected through text analysis includes relevant strategies and reports, press releases, news articles, and scientific and academic literature. As the researcher’s previous knowledge in the field influences the learning outcome and understanding of the concepts and information collected from interviews, I made sure to gain a solid understanding of the field of research and industry dynamics before conducting the interviews. Additionally, I attended two conferences and worked for four months at the World Exposition in Dubai. I gained valuable knowledge on topics and perceptions relevant to the research study through observation studies.

Triangulations have been used to build credibility to the key findings of the analysis. Data from semi-structured interviews are either verified by several informants or underbuilt by secondary data. Similarly, secondary data are either verified by several independent sources coming to the same conclusions or supported by key findings from interviews.

4.2.1 Semi-structured interview

Semi-structured interviews are widely used in qualitative research to develop new and significant knowledge in a field of research. The semi-structured interviews revealed valuable information and allowed me to understand better the potential of green and autonomous technology for maritime transport in Norway. Kvale and Brinkmann (2015) identify seven stages of conducting in-depth interviews: thematizing, designing, interviewing, transcribing, analyzing, verifying, and reporting. These stages have been used as guidelines when preparing the interview guide and conducting and organizing data to ensure a good research approach and structure in the analysis.

The semi-structured interview has several advantages, but it is also time-consuming and, as mentioned, requires the interviewer to prepare and do research in the field of interest before conducting the interviews. Additionally, it is up to the interviewer to ensure the reliability and confidentiality of interviews and the analysis in general (Kvale & Brinkmann, 2015). As mentioned, the geographical context of the study is Norway. This means that external factors can be overlooked in the analysis, e.g., development in other countries, new regulations, or how the overall global economic stability influences the TIS.

4.2.1.1 Conducting and transcribing the interviews

In preparation for the interviews, five themes of particular interest were identified:
1) General insight – interest, past development, and TIS structural components
2) Innovation and development – pilot projects, motives, and development patterns
3) Business opportunities and application – key drivers and barriers
4) Regulations – legitimacy and regulatory frameworks
5) Expectations – market prospects and overall TIS functionality

Together with the Consent Form, these five themes were sent to the participants in advance. The interviews lasted between 35 and 67 minutes. I took notes to complement the recordings to ensure that thoughts, observations, and immediate personal reflections were preserved. Even though the interview guide shaped the interview process to a certain degree, I tried to keep the interviews conversational. I made sure not to ask multiple or leading questions, as a good interviewer should avoid asking multiple or leading questions (Kvale & Brinkmann, 2015). On the other side, according to Kvale and Brinkmann (2015) is the interviewer´s ability to be a good listener and ask follow-up questions a good characteristic. I, therefore, wrote down keywords during the interview so I could ask follow-up questions where it felt natural. I also made sure to give the informants time to reflect.

Additionally, I had the informants clarify information and terms that came across as unclear to ensure that all information was preserved correctly. Each question in the interview guide was given a code, linking it to the relevant function in the empirical analysis. This ensured that the information collected was relevant and well-suited for the study.

After the interviews were conducted, transcribing the interviews allowed me to understand better the data collected, which alleviated the process of organizing the data (Kvale & Brinkmann, 2015). Transcribing provides a more thorough examination of the data collected and helps identify possible biases of the researcher (Bryman, 2012). With that said, transcribing interviews is time-consuming, and I strongly considered passing this stage due to time constraints; however, the quality of the interview reports can determine the ability of new research and interpretations being made (Kvale & Brinkmann, 2015), I, therefore, concluded it would be a necessary step to ensure the quality of the research design. After the first transcriptions were finalized, the importance of this process became apparent to me, as valuable information was collected and I came closer to the data.

As all the informants had Norwegian as their native language the interviews were conducted in Norwegian. This allowed the participants to speak more freely.

4.2.1.2 Informants and sampling

Informants for the semi-structured interviews were selected based on their ability to contribute to a broader understanding of the TIS of green autonomous technology and the potential of implementing such technologies in maritime transport systems in Norway. Table 1 provides an overview of the informants and the assigned letter used in the analysis.

Table 2: Overview of informants for semi-structured interviews

Description	Assigned letter
Regional cluster in the field of autonomous technology	Informant A
National cluster in the field of clean and renewable energy for maritime sector	Informant B
Global cluster representing the entire value chain of shipping in maritime sector	Informant C
A company established for remote operation of autonomous vessels	Informant D
A large firm and leading technology provider in maritime sector	Informant E
Public funding and support enterprise	Informant F
Administrative and supervisory authority in maritime sector	Informant G
Forum for autonomous ships	Informant H
A national agency with responsibility of maritime safety, management and emergency preparedness	Informant I
A company involved in the development of autonomous technology for the ferry segment	Informant J

4.2.2 Document analysis

To a certain degree, qualitative research is based on the interpretation of information by a single researcher and its ability to process and draw conclusions on similarities and differences within the field of research (Kvale & Brinkmann, 2015). Documents supporting the findings are essential to establish credibility in the analysis (Bowen, 2009). Furthermore, there should also be a high correlation between the data used and what is being investigated to ensure a high degree of validity (Kvale & Brinkmann, 2015). When conducting the qualitative document analysis, several documents were selected. The selected documents support and validate findings from the primary data and contribute with additional perspectives and insight not addressed during the interviews.

The selected documents for the document analysis can be found in Appendix C.

4.2.3 Temporary clusters of knowledge development

During the research study, I participated in two conferences: NorShipping Conference, an international conference in Lillestrøm, Norway, and Trondheim Tech Port Conference, taking place in Trondheim, Norway. Furthermore, I worked at the Norwegian pavilion at Expo 2020 Dubai, in UAE, for over four months promoting Norway as a pioneer in sustainable ocean solutions and showcasing the newest technology within the field. Attending these temporary clusters, I made valuable observations through several business meetings and seminars and conversations with several business representatives within the industry. In this process, I made sure to take notes and write down perceptions and topics that would be interesting to research further. After organizing and verifying this data, through e.g., triangulation, key findings were used in the analysis.

4.3 Analysis method

As previously explained, The TIS framework is a theoretical perspective and a way of identifying TIS structural components (network, institutions, and actors) and functions within an innovation system. Bergek, Jacobsson, Carlsson, et al. (2008) identify seven functions for analyzing the functional dynamics of TISs. Still, to a certain extent, it is up to the researcher to determine the function of most relevance when organizing the data collected. Data can also overlap several functions, which presents some challenges. At the beginning of the research study, I spent substantial time understanding what processes took place within each function and how to link data to the correct function in the analysis.

To establish an initial overview of the TIS structural components and functions within the TIS of green autonomous technology, I started by mapping the TIS structural components to get an overview of their proximity and interconnectedness. I then drew a second map outlining the functions and wrote a brief description of what processes took place within each function and the data that would be of most relevance. When collecting primary and secondary data, I developed a system for coding relevant data and linking it to the correct function in the analysis. This provided me with a tool in the process of organizing the data.

4.4 Quality of the research design

Validity can be referred to as the degree to which the researcher's findings correspond to the questions asked (Tjora, 2021), and a strong validity and reliability of the analysis are essential to ensure the quality of the research design (Bryman, 2012; Yin, 2003). The interview guide was prepared following the research methodology for qualitative interviews (Kvale & Brinkmann, 2015). Informants were thoroughly selected based on their relevance in the field. The interview guide questions were coded to TIS functions to ensure the relevance of the data collected. Table 2 provides an overview of the informants selected, and Appendix C presents the documents used to support the primary data in the analysis.

As mentioned, the theoretical perspective of TIS is a relevant research methodology for sustainability transitions studies, and one of two frameworks for analyzing prevailing socio-technical structures (Truffer & Coenen, 2012). However, in terms of reliability, can sustainability transition studies be hard to duplicate as TIS are dynamic systems that are constantly changing. Conducting a TIS analysis requires attention to both structural dimensions and functions of the respective innovation system. Therefore, the researchers can only give qualified assumptions about the technology based on the assessment of the TIS at the time of the research study. Consequently, it will be hard to test findings and facilitate others to come to the same conclusion.

4.5 Limitations

The chosen research methodology and processes of data collection present some limitations. As mentioned, some of the primary and secondary data have been obtained in Norwegian and later translated into English by me, which allows for errors or information to be lost in translation. With that said, the citations used in the analysis, including subsequent additions and omissions by the author, have been approved by the informants after translation. Additionally, data collection was influenced by time constraints and the scope of the analysis. Transcribing of interviews, for example, came at the cost of more substantial document analysis. Moreover, the fact that data can overlap several of the functions in the empirical analysis can present some challenges to the research design.

In terms of document analysis, a few limitations can be observed. First, some documents are not retrievable, complicating access to information (Bowen, 2009). Then there is also a chance that vital information has been blocked from the general public, as the documents might originally have contained information of high competitive value. In addition, the researcher’s previous knowledge in the field can influence the researcher’s ability to interpret data and draw conclusions (Bryman, 2012; Tjora, 2021), and even though document analysis can improve the interpretation of the data collected a biased selection of data can also influence the results of the analysis (Bowen, 2009).

4.6 Ethical considerations

In line with NSD guidelines, have the informants' identities been kept confidential and data been handled according to privacy regulations (NSD, 2022). As seen in Table 2, each informant has been assigned a letter for use in the empirical analysis. Additionally, data material has been stored on an external server, and the names of the participants have been held on a separate list, separate from other data. With that said, there is a chance that information can be traced back to an informant. I want to underline that this has been discussed with the informants, and precautions to minimize this risk are taken.

In addition, it is essential that considerations concerning informed consent are respected and that the informants receive sufficient information about the project to decide whether or not to participate (Bryman, 2012). The Consent Form, Appendix B, is the information letter used in the research study, and it was submitted and approved by NSD before the project started. The Consent Form was based on the NSD template and explained the project and how the confidentiality of the informants are, and will be preserved after the research project. It also gives information about the ability of participants to withdraw from the project at any given time without justification. The Consent Form was sent to the selected informants, and a signature was requested before the interview. In addition, oral consent was requested to start the recording at the beginning of the interviews to establish trust and ensure that the terms and conditions were understood correctly.

5 Empirical analysis

This analysis builds on the theoretical perspective from the sustainability transition and innovation studies research traditions. It understands transformation as a response to societal and technological pressure, leading to systemic changes. As mentioned, favorable societal and economic conditions are typically needed for a breakthrough of radical innovations (Köhler et al., 2019) and the twin transitions of digitalization and sustainability have been identified as two such favorable social and economic conditions influencing the development of green autonomous technology for maritime transport in Norway.

Applying the TIS framework (Bergek, Jacobsson, Carlsson, et al., 2008), the research study investigates the TIS of green autonomous technology in functional terms. The analysis begins by briefly summarizing the technological field of interest. Secondly, it presents an overview of the unique combination of TIS structural components. Then, an assessment of the overall system performance will be determined through an empirical mapping of seven functions. Key findings from the empirical analysis will be discussed in chapter six.

5.1 Defining the technological field

Maritime transport can, as previously described, be conceptualized as a socio-technical system in which the different elements of the system interact, and together they provide services for society (Markard et al., 2012a). Therefore, the introduction of green autonomous technology in maritime transport systems can lead to fundamental changes in existing transport systems, as seen in the uptake of battery-electric solutions in coastal shipping (Bergek et al., 2021; Markard et al., 2012a). The TIS of green technologies has received more momentum than the TIS of autonomous technology. However, an increased interest in combining the two technological fields to develop new and better transport systems can be observed. This research study is the first of its kind, as it researches the two technologies under one scope through a TIS analysis.

As explained in Chapter 1.1: Introduction to the field, green- and autonomous technologies are not directly linked; however, autonomous technology is often implemented on new ships in combination with green technologies, making the vessel both low-or zero-emission and autonomous. Maritime transport is highly heterogeneous, which means that the technology will likely be more feasible in some segments than others (Bergek et al., 2021). Identifying these key segments is therefore crucial for the implementation of new technology. This research study aims to contribute to new knowledge about the benefits of implementing such technologies in maritime transport systems in Norway and identify system dynamics influencing the TIS today. In this regard, feasible segments for application, system building activities, and blocking mechanisms will be identified.

5.2 Structural components and their influence

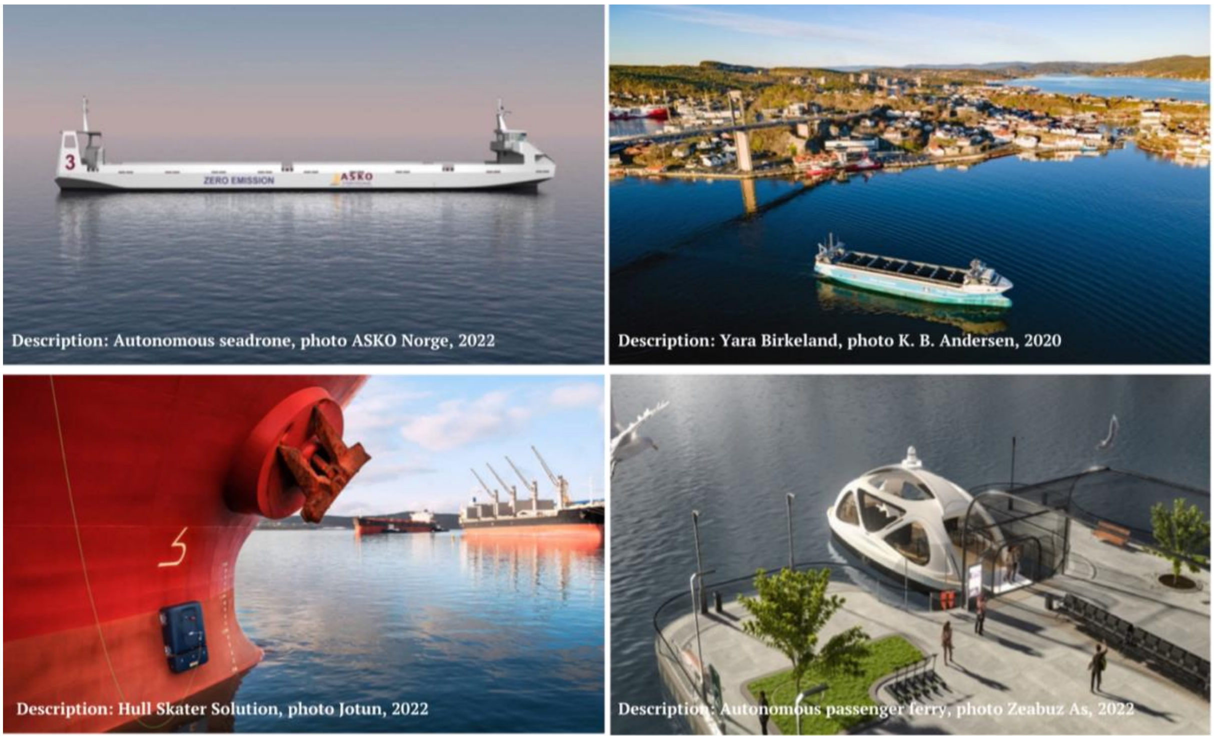
This chapter identifies structural components within the TIS of interest and aims to understand how the unique combination of TIS structural components has, and is, influencing the TIS. TIS structural components were identified by collecting and reviewing primary and secondary data and organized under the three categories of components of an innovation system; actors, networks, and institutions (Carlsson & Stankiewicz, 1991). While the analysis does not list all the TIS structural components, it aims to give a clearer picture of the different types of structural components within the three categories and give examples. Worth mentioning is that TIS structural components can simultaneously be part of several innovation systems (Bergek, Jacobsson, & Sandén, 2008). Their involvement in one TIS does not exclude them from being part of another TIS or knowledge network. On the contrary, I argue that this may create bridges as it allows structures to tap into and diffuse knowledge.

5.2.1 Actors

Actors within the TIS of green autonomous technology for maritime transport interact by communicating, exchanging, cooperating, and competing. As mentioned, the development of new technologies is characterized as capital intensive, which is why larger firms are often heavily represented in this phase. What is of particular interest within the TIS of green autonomous technology for maritime transport is that the TIS structural components consist of a mix of small and large firms. Still, unlike other emerging TIS, large firms from established TIS are heavily represented in the entrepreneurial activities within the TIS today. Researchers, universities, and international actors have also shown interest in the technology and entered into the TIS, enriching the innovation system further.

The most central actor within the TIS is the Kongsberg Group. With a history dating back to 1814, Kongsberg has been involved in the development of autonomous technology since the beginning and is today a leading technology provider in the maritime sector (Kongsberg, 2022). In 2018, Kongsberg joined forces with Wilhelmsen (a strong shipping and logistic group) through a joint venture to establish the world´s first company set to operate autonomous vessels, Massterly (Wilhelmsen Group, 2018). With a name originating from the IMO definition "Maritime Autonomous Surface Ship (MASS)," Massterly, like Kongsberg, is today involved in several ongoing projects in Norway. Kongsberg holds a unique position within the TIS, offering a complete value chain for autonomous ships, ranging from design and development to control systems, logistics services, and vessel operations (Kongsberg, 2022).

The involvement in the field of research by the companies Yara and ASKO, on the other hand, might not be as apparent. Yara is a global crop nutrition company (Yara, 2022a), and ASKO is Norway's leading grocery distributor (ASKO, 2022). Intending to strengthen their supply chains, these two companies are today involved in two of the leading projects in the world featuring green autonomous technology for maritime transport. Yara with the world's first zero-emission and autonomous container vessel, Yara Birkeland (Yara, 2017), and ASKO with the development of two sea drones which hold the potential to cut carbon emissions by 5000 tons annually (Kongsberg, 2020c). Another large firm that found interest in the technology relatively early was Jotun. Jotun is the world's leading provider of paint systems and marine coatings, and in 2015, Jotun joined forces with Kongsberg Maritime to develop a revolutionary climate-friendly hull cleaning solution (Kongsberg, 2020a) All these companies illustrate an interest from actors entering the TIS from established sectors and innovation systems with a willingness to invest in the technology. Other relevant actors to mention are, e.g. Marine Technologies, with their superior vessel control and communication solutions (Marine Technologies, 2021-22), and VARD, one of the prominent global designers and shipbuilders of specialized vessels (VARD AS, 2022).


Description: Autonomous seadrone, photo ASKO Norge, 2022

Description: Yara Birkeland, photo K. B. Andersen, 2020

Description: Hull Skater Solution, photo Jotun, 2022

Description: Autonomous passenger ferry, photo Zeabuz As, 2022

Figure 2: Four of the leading projects in Norway in the field of green autonomous technology for maritime transport

In the ferry segment, the role of SMEs and start-ups are of particular interest. An actor who is taking a lead in the development within the passenger ferry segment is Zeabuz. Zeabuz is a spin-off from the Norwegian University of Science and Technology (NTNU) and is a relatively new actor in the field, established in 2019 (Zeabuz AS, 2022). The company was involved in developing advanced technology for the world´s first full-scale autonomous urban ferry prototype "MilliAmpere 2", and have high ambitions in terms of utilizing autonomous electric passenger ferries to create better transport systems in urban waterways (Zeabuz AS, 2022). Hydrolift Smart City Ferries, with the electrical and autonomous ferry project Hyke (Hyke, 2022) and Maritime Robotics, a leading provider of unmanned solutions, are other actors that should be mentioned (Maritime Robotics AS, 2019-22). Public procurements have been crucial in the uptake of battery-electric solutions for the ferry sector to date, and by the end of 2022 it has been stated that Norway will have over 80 battery-electric ferries in operation (Bach et al., 2020; Haugland et al., 2022).

5.2.2 Networks

Networks can be of various types and are important structures for knowledge spillover and tacit learning to take place between actors. Networks are in this analysis organized into national networks, joint ventures/ collaborations, and international knowledge networks.

5.2.2.1 National networks

The formation of clusters on a national and regional level can be an important structure to strengthening the functionality of the TIS as it facilitates a platform in which actors with similar interests can join forces and explore the technology. On a national level, Norway Innovation Cluster (NIC) plays a key role in the diffusion of new technology and contributes to value creation by increasing cluster dynamics and individual firms' ability to innovate (Ministry of Trade & Energy, 2017). The program is government-funded and managed by Innovation Norway, Siva, and The Norwegian Research Council (Innovasjon Norge, 2022b).

Nationally are clusters like the Norwegian Center of Expertise Maritime CleanTech (NCE MCT) working to establish sustainable innovation projects with commercial potential. The cluster uses Norwegian maritime expertise as a springboard for the development of new energy-efficient and environmentally friendly technologies (Maritime CleanTech, 2018). Such clusters "take bold steps in the direction of green solutions for the shipping industry" (Informant B). On a regional level is clusters like Ocean Autonomy Cluster relevant to mention as they contribute to the innovation and development of autonomous ocean solutions through cluster activities. Established in 2019, Ocean Autonomy Cluster (OAC) is today Norway's leading hub for expertise in regard to ocean autonomy, and the cluster consists of a range of actors from technology suppliers to investors and key customers (Ocean Autonomy Cluster, 2022). In addition, SAMS Norway and ITS-Norway are relevant to mention. SAMS Norway is the Norwegian business cluster for autonomous mobility and transport systems, and one of its main goals is to "Contribute to building attractive test arenas for autonomous systems in order to develop, test, verify, and certify new solutions" (SAMS Norway AS, 2020a). ITS-Norway is a membership association that aims to "promote smarter, safer and more sustainable transport" (ITS-Norway, Nd) ITS is an abbreviation for Intelligent Transport Systems, technology that will play an important role in developing smart cities and the next-generation logistics and mobility solutions (ITS Norway, 2022).

In addition to clusters are also forums like The National Forum for Autonomous Ships (NFAS) important networks for the development and diffusion of new technology on a systematic level. The forum was established in 2016, and today, NFAS plays a key role in knowledge development and diffusion of autonomous technology through collaborative networks with the EU and by hosting seminars and conferences for members and others interested in the technology (Maritime Safety Committee, 2018; NFAS, 2022). NFAS is also actively working to place autonomy on the political agenda internationally and to highlight the importance of autonomous ships as a key attribute for future maritime transport system (NFAS, 2022)

Additionally are activities in three areas in Norway standing out in particular in terms of entrepreneurial activities and clustering of actors with interest in the field. These are the Trøndelag region, with Trondheimsfjord, the Møre region, with Storfjorden, and Horten. The Trondheimsfjord is home to the world´s first test arena for autonomous vessels, established in 2016 (Testsitetrd, 2017). NTNU and SINTEF have a strong presence here, and a new ocean space center is under planning which will strengthen the region's role in the development further. "In the context of autonomous ships, Trondheim has the world´s most important technology environment with a strong collaboration between industry, research, and academia" (Informant H). In terms of the Møre regions, are universities also here, working closely with the maritime sector to drive innovation and development within the field. The maritime cluster in Norway's Møre region is at the global forefront of maritime technology and operations, and in 2018, Storfjorden, near Ålesund opened as the second test area for autonomous ships in Norway (SAMS Norway AS, 2020b; ÅKP, 2017)

Following the development in the Trøndelag and Møre region, a third test area was established in Horten, in 2018, for remote control and autonomous ship testing. Kongsberg Maritime, Norwegian Defence Research Establishment (FFI), and the University of South-Eastern Norway (USN) have all a strong presence in this region (SAMS Norway AS, 2020b; USN, 2018). More recently, activities in a fourth test area, Haugesund in South-Western Norway, started to be formed. A test area was established here as late as 2021 (Moderne

Transport, 2021). Entrepreneurial activities in these areas, in particular, can increase competitiveness as valuable knowledge development and diffusion of the technology can take place, and expectations can be formed (Ocean autonomy cluster, 2021).

Another form of the network are temporarily clustering of knowledge (e.g., conferences, webinars, and summits) in which learning can take place about the technology. While this thesis does not provide an overall assessment, I want to highlight a few that I attended to collect data for this research study. The Third International Ship Autonomy and Sustainability Summit were arranged in Lillestrøm, Norway, in April 2022. The summit was organized by NFAS in cooperation with the European Commission's Directorate General for Transport (DG MOVE) and SINTEF (Nor-Shipping, 2022). Another conference was Trondheim Tech Port which took place at the end of March this year. Trondheim Tech Port is an innovation district located in Trondheim, Norway, that gathers industry, research centers and universities, the public sector, government organs, the public, investors, and start-ups to accelerate innovation within technologies (Mallon, 2022). Ocean autonomy Cluster also arranged a three-day conference in Trondheim, Norway, in August of 2021, focusing exclusively on autonomous technology. According to their website, the conference will be held again in September this year (Ocean Autonomy Cluster, 2022). Overall, the main takeaway from these events was that autonomy is not a goal in itself, but a means to realize new and better maritime transport systems.

5.2.2.2 Joint ventures and partnerships

In terms of joint ventures, there are a handful of projects with significant influence on the functionality of the TIS. What many of them have in common is Kongsberg´s involvement.

Characteristics for more extensive projects are well-established actors entering from other sectors or innovation systems to utilize the technology to improve their logistic operations. Some of the joint ventures of particular importance in this category are:

Yara and Kongsberg to build YARA Birkeland announced in 2017 (Yara, 2017).

- Jotun and Kongsberg to develop the Hull Skater Solution announced in 2015 (Kongsberg, 2020a).
- ASKO, Massterly and Kongsberg with the plan to build two sea drones, announced in 2020 (Kongsberg, 2020c).
- Ekornes As, DB Schenker, and Naval Dynamics with the plan to build a Zero-emission Autonomous Coastal Container Feeder announced in May 2022. Kongsberg and Massterly are also involved in this project (DB Schenker, 2022).

Also in the ferry segments, interesting joint ventures and partnerships can be observed:

- Zeabuz involvement in the NTNU project MilliAmper 2 (Zeabuz AS, 2022).
- Hurtigruten announced its partnership with SINTEF to create zero-emission ships for the Norwegian coast in March 2022 (Vikan, 2022a).
- The Hydrolift Smart City Ferries project through Hyke (Hyke, 2022).
- Zeabuz and Torghatten to develop passenger ferries (Horntvedt, 2021).

Additionally, the establishment of Massterly, the joint venture between Kongsberg and Wilhelmsen, in 2019 marked a significant shift within the TIS as it opened an opportunity for pilot projects to be carried out and ships to gradually build up its autonomous capabilities (Wilhelmsen Group, 2018). Massterly serves a vital function in the TIS as the world´s first company set to operate autonomous vessels(Massterly, 2022).

5.2.2.3 International networks.

Internationally the network around IMO (the United Nations specialized agency responsible for the safety and security of shipping) is central to the development. Competition between countries and formal and informal networks with global ties is also a great driver for innovation and development within the TIS.

A Norwegian cluster relevant to this category is the Global Center of Expertise Blue Maritime. The Norwegian government awarded the cluster the Global Center of Expertise (GCE) status for its unique global market position and its important contribution to Norwegian value creation (ÅKP, 2016). Today, the cluster initiates several activities (e.g., strategic collaborative projects) to ensure that Norwegian maritime industries will contribute with solutions to combat the climate crisis. The cluster's New Blue Deal strategy was launched in June 2021 and is serving as the compass in this work (GCE Blue Maritime, 2021). Additionally, the Norwegian Maritime Exporters (NME) has, since 1995, served as a vital link between Norwegian maritime companies and the global markets (Norwegian Maritime Exporters, 2022).

As mentioned, can also temporarily clusters (e.g., conferences and World´s Fair) contribute to knowledge development and diffusion. The World Exposition takes place somewhere in the world every fifth year, and nations worldwide are participating and showcasing their newest technologies within designated fields (BIE, 2022). Over six months, from October 2021 to April 2022, EXPO 2020 took place in Dubai, UAE. Norway was participating with the theme "Norway pioneering sustainable ocean solutions" (Norway Expo Dubai, 2020), and developments within the TIS of green technology and the TIS of autonomous technologies were showcased to an international audience.

> The purpose of World Expositions is to promote international relations through uniting world countries with the exchange and exposure of ideas, new thoughts, innovation, and experience in business, education, research, and technology (Innovasjon Norge, n.d)

Norway aims to be the leading nation in developing sustainable ocean solutions like green autonomous transport, but countries like the Netherlands, USA, Belgium, Germany, and Finland are also positioning themselves in the technological development of green autonomous technology. As of 2018, they all had approved test areas for autonomous vessels within their own country (INAS, 2022). Korea, China, and Singapore are also involved, even though development in these countries is harder to trace.

5.2.3 Institutions

Sectors have formal and informal institutions that specify the "rules of the game" (Geels, 2004; Malerba, 2002). Whereas formal institutions refer to rules and regulations, support policies, and procurement practices (e.g., agreed-upon standards, formal processes), informal institutions encompass norms, values, and beliefs that guide actors' cognition and practices, e.g., routines and expectations. In the maritime sector, legislation institutions are particularly important, as regulatory frameworks and standards are issued at national and international levels.

Norwegian Maritime Authority (NMA) and the Norwegian Coastal Administration (NCA) are government authorities with substantial influence on the development of new technology within maritime sectors (NCA, 2022; NMA, 2022b). NMA participates in several international forums, and represents an important common good for society as its activities include governance and administrative tasks related to laws and regulations (NMA, 2022a).

NMA also works to place autonomous ships on the agenda on an international scale and aims to be a catalyst for development through in-house expertise and close collaboration with industry partners (NMA, 2022b). NCA is a transport agency under the Ministry of Trade, Industry, and Fisheries, and ensures safe and efficient traffic along the coast and into ports (NCA, 2022). NCA is in charge of the maritime component of the National Transport Plan (NTP) and can, therefore, greatly influence the technology's development by e.g., pointing at the technology as a solution to improve existing transport systems. These two actors are, in other words, necessary in the verification and legislation of new technology, and their support is essential for technologies to gain ground.

Internationally, IMO is in charge of the guidelines and standards for all maritime activity. Today IMO works closely with EU countries through the Maritime Safety Committee to update current regulations to support the technological developments within the industry (IMO, 2018; Maritime Safety Committee, 2021). Actors within the TIS, most of them members of NFAS, are joining forces to get autonomous technologies on the IMO agenda internationally (Maritime Safety Committee, 2018; NFAS, 2022).

Another type of formal institution is financial institutions and support policies, consisting of various organizations and government-funded enterprises. Institutions referred to in this thesis are, e.g., The Norwegian Research Council, Innovation Norway, and SIVA. The Norwegian Research Council provides financial support and advice for research and innovation projects and aims to drive development through research and innovations. The aim is to "promote to promote a society where research is created, used and shared, and thus contributes to restructuring and enhanced sustainability" (RCN, 2022b). Innovation Norway is the Norwegian Government's most important instrument for innovation and development of Norwegian enterprises and industry. It contributes to Norwegian businesses' sustainable growth and exports through capital and expertise (Innovation Norway, 2022). Siva is a governmental enterprise that facilitates growth and development in Norway by facilitating a strong regional infrastructure for innovation consisting of, e.g. business incubators, business gardens, and research- and technology parks (SIVA, 2022). The Siva structure is an integral part of the national structure for innovation, together with Innovation Norway and The Norwegian Research Council.

Enova is another government-owned institution that should be mentioned. Enova acknowledges that it can be costly and risky for individual businesses to start using the new and climate-friendly technologies. Therefore, it allocates funding to these projects so sustainable projects can be implemented and yet be economically viable (ENOVA, 2018). Enova utilizes a technology readiness level (TRL) scale to estimate the maturity of technologies and is today funding projects typically in the higher levels of the scale (TRL 7-8) in which the technologies are introduced to the market (ENOVA, 2022). Enova is also involved in funding programs such as PILOT-E, a collaboration between the Norwegian Research Council, Innovation Norway, and Enova to accelerate the time to market for cutting-edge technologies (Grünfeld et al., 2020).

NTNU and SINTEF have since 1950 cooperated to bring industry and academia closer together. The Norwegian University of Science and Technology (NTNU) is Norway's largest university responsible for higher education in Norway (NTNU, 2022). It is the nation's forefront institution for educating engineers, and several projects in the development of green autonomous technology have originated from NTNU. The University also has an Autonomous Marine Operations and Systems center, NTNU AMOS. SINTEF, on the other hand, is an independent research organization and one of the largest contract research institutions in Europe (SINTEF, 2022). NTNU and SINTEF facilitate world-leading laboratory and test facilities in a wide range of technological fields.

5.3 Functions

This thesis aims to contribute to understanding the processes taking place within the TIS of green autonomous technology for maritime transport in Norway. As mentioned in chapter 3.3. are the following seven functions used when mapping key-innovation related processes: 1) Knowledge development and diffusion, 2) Entrepreneurial experimentation, 3) Market formation, 4) Influence on the direction of search, 5) Resource mobilization, 6) Legitimation and 7) Positive externalities (Bergek, Hekkert, et al., 2008). With that said, the functions are closely related, and processes can influence several of the functions simultaneously or over time, shaping system dynamics.

The following section describes processes taking place within each function, identifies key mechanisms influencing the functionality of the TIS, and evaluates function strength based on key findings. How functional patterns are linked to inducement and blocking mechanisms (e.g. challenges related to public acceptance, acceptable risk levels, efficient design, and approval processes) are also discussed. The empirical analysis ends with a summarization of the overall assessment of the TIS.

5.3.1 Knowledge development and diffusion

As mentioned, the knowledge development and diffusion function is concerned with the breadth and depth of the knowledge base of the TIS and how well that knowledge is diffused and combined within a system (Bergek, Jacobsson, Carlsson, et al., 2008). Moreover, it allows for the identification of critical knowledge gaps. This chapter explains the crucial role of actors and networks in facilitating learning and for processes to be set in motion to support the development of technologies within the TIS.

In Norway, knowledge about autonomous technology for maritime transport started to develop due to the MUNIN project, a collaborative research project co-funded by the European Commissions under its Seventh Framework Program (MUNIN, 2016). When the project results were published in 2016, valuable insight into the various benefits and limitations of implementing the technology in maritime shipping was presented. The results also disclosed that compared to a conventional manned bulker, the autonomous bulker would be commercially viable under certain circumstances (MUNIN, 2016). Following the presentation of the MUNIN project, an interest in forming a forum focusing on autonomous ships evolved. Several challenges had been identified, and the perception among actors was that these challenges would be better addressed together by the industry as a whole. As a result, the Norwegian Forum for Autonomous Ships (NFAS) was established in 2016 (NFAS, 2022). Knowledge diffusion is, as previously described, one of the prerequisites for learning to take place at a systemic level (Lundvall, 1992). Today, NFAS, accompanied by several other actors, is working together to create momentum around the technology both on a national and international level. Furthermore, the need to overcome general challenges, e.g., public acceptance, acceptable risk levels, efficient design, and approval processes, regarding autonomous technology are as relevant today as they were in 2016.

In the National Transport Plan published in 2017 (Ministry of Transport, 2016-2017), autonomous technology for maritime transport, in combination with green technology, was one of the areas given attention. This presents one of the first institutional changes as strategies were put in place to develop and diffuse knowledge about the technology and the potential of implementing such technologies in future maritime transport systems. "The work that was started around autonomy related to National Transport plan, was based on the MUNIN project. The results of the project were newly published, and was the foundation for this work" (Informant I). Green autonomous technology for maritime transport are today depending on both public and private sector involvement to initiate processes in regards to knowledge development and diffusion. A number of public reports and strategies have been published since autonomy started to gain momentum back in 2016, however, the focus has mainly been on green technologies (i.e. electrification and alternative fuels) whereas green autonomous technologies have received little attention. Knowledge is a fundamental resource in the modern society (Lundvall 1992) and the fact that solutions featuring both green- and autonomous technology have received little attention, can influence the adaption of such technologies substantially. Action should therefore be taken on a government level to bridge this knowledge gap.

> "There are two things you want to achieve with autonomy. The first is for conventional ships to provide better decision support to the crew to increase efficiency and safety…The second is that it can be interesting to make certain ships unmanned" (Informant H).

The Norwegian society trusts the government, and solutions presented in government papers and strategies typically receive substantial legitimacy. A competitive, safer, and greener shipping is why autonomous ships should be part of future maritime transport systems Felt (Rødseth & Nordahl, 2018). These advantages should be given more attention in the transition of the maritime transport system. Adding to that, defining different levels of autonomy and feasible areas for application can change the interpretation of the technology to less threatening. Ensuring that the general public understands that different levels of autonomy that will be applied would be necessary for the process of gaining social acceptance as miss interpretations can create resistance towards the technology. A strong collaboration between industry, academia, and government, referred to as the Triple Helix model (Strand & Leydesdorff, 2013), are key attribute in this process as it facilitates networks in which industry issues are brought into the classrooms and knowledge can be shared with industry actors for them to act on. Green autonomous technology relies heavily on a skilled and educated workforce, and significant investments are today needed in education, training, and competence building to complement the technology. Therefore, public funding and support and the involvement of research and development institutions hold an essential role in this regard. "Universities like NTNU play a role in the diffusion of technology" (Informant E).

Another way to achieve knowledge diffusion is by forming clusters (Balland et al., 2016; Giuliani, 2005). Clusters connect actors with similar interests and members can benefit from, e.g. the development of tacit learning and knowledge diffusion (Gertler, 2003). "Our role as a cluster is to bring new knowledge to the table" (Informant C). Cluster absorptive capacity refers to the ability of firms to absorb external knowledge and diffuse it into the intra-cluster expertise, a process essential for new learning to be developed (Giuliani, 2005). "Through the cluster program, we aim to connect actors into a bigger network, and be involved in driving innovation processes forward" (Informant A). Actors with a vested interest in multiple TISs can also tap into and diffuse knowledge between TISs. "In Norway, there are often positive attitudes towards collaborations" (Informant B). Moreover, knowledge spillovers from other transport sectors, e.g., the automotive industry and air transport, can also build new knowledge, as some of the same challenges often can be observed between industries in the transformation into more efficient and sustainable sectors (Mäkitie et al., 2020). "You would think that it was much more challenging to drive on a busy road than on a large sea" (Informant C).

To summarize, public and private sector involvement has been essential in knowledge development and diffusion of green autonomous technologies for maritime transport. Still, it can be argued that solutions featuring both green- and autonomous technology have received little attention. Norway can benefit from a skilled and educated workforce and good attitudes towards collaboration; however, new jobs will be developed that demand different skill sets. Significant investments are therefore needed in skill-upgrading and competence. The function is assessed to intermediate.

5.3.2 Entrepreneurial experimentation

Building on the first function, the phase of entrepreneurial experimentation allows for expectations to be formed and a social learning process to unfold in which some technologies and firms will fail while others succeed (Bergek, Hekkert, et al., 2008). Entrepreneurial experimentations of green autonomous technology are today influenced by the fact that the technology is immature. "It is still in a developing phase, and there are several challenges that still need to be addressed… However when we first overcome these challenges, I believe it will be easy to scale up" (Informant E). "It is an immature market with great growth potential» (Informant C). In addition, a standardized approval process for autonomous operations is addressed by several actors as one of the main challenges in the process of entrepreneurial experimentation. In response to this challenge, an alternative design process has been developed to support new projects and ensure that the technology being developed meets sufficient safety requirements.

The entrepreneurial experimentation function refers to exploring and exploiting business opportunities based on new technologies and applications (Coenen, 2010). MUNIN became an important project in a Norwegian context (Rødseth et al., 2022). A significant shift within the TIS could be observed as expectations toward the technology were formed. MUNIN is an abbreviation for Maritime Unmanned Navigation through Intelligence in Networks (MUNIN, 2016). "Interest for autonomous technology was present in the cluster in 2010, but it was first in 2015 it started to scale up" (Informant C). In addition, increased interest from actors to enter the field could be observed. Similarly, were the collaboration between NTNU and, e.g., Zeabuz in developing the first full-scale autonomous ferry prototype, MilliAmpere 2, an important project forming expectations in the ferry segment. "Based on the experience gained from the success of MilliAmpere, NTNU decided to design a full-scale prototype of a passenger ferry, MilliAmpere 2"(Informant J). Zeabuz is today one of the leading firms in developing autonomous technology for the passenger ferry segments (Zeabuz AS, 2022).

Today, several projects are under development, and the first zero-emission autonomous container vessel (Yara Birkeland) is operating in Norwegian waters, gradually building its autonomous capacity (Stensvold, 2022). "On the technical side, a natural evolution occurs – more knowledge is being developed" (Informant E). "It is right to look at the projects under development. YARA Birkeland, for example, is short distance fright transport going back and forth between two, or a few harbors" (Informant G). With that said, investments in new technologies are, as mentioned, often capital intensive and demand investments in complementing infrastructures. Particularly important for the function of entrepreneurial experimentations is the infrastructure in which the technology can be tested and verified. Four areas have been approved to test autonomous technology in Norway (INAS, 2022; Moderne Transport, 2021).

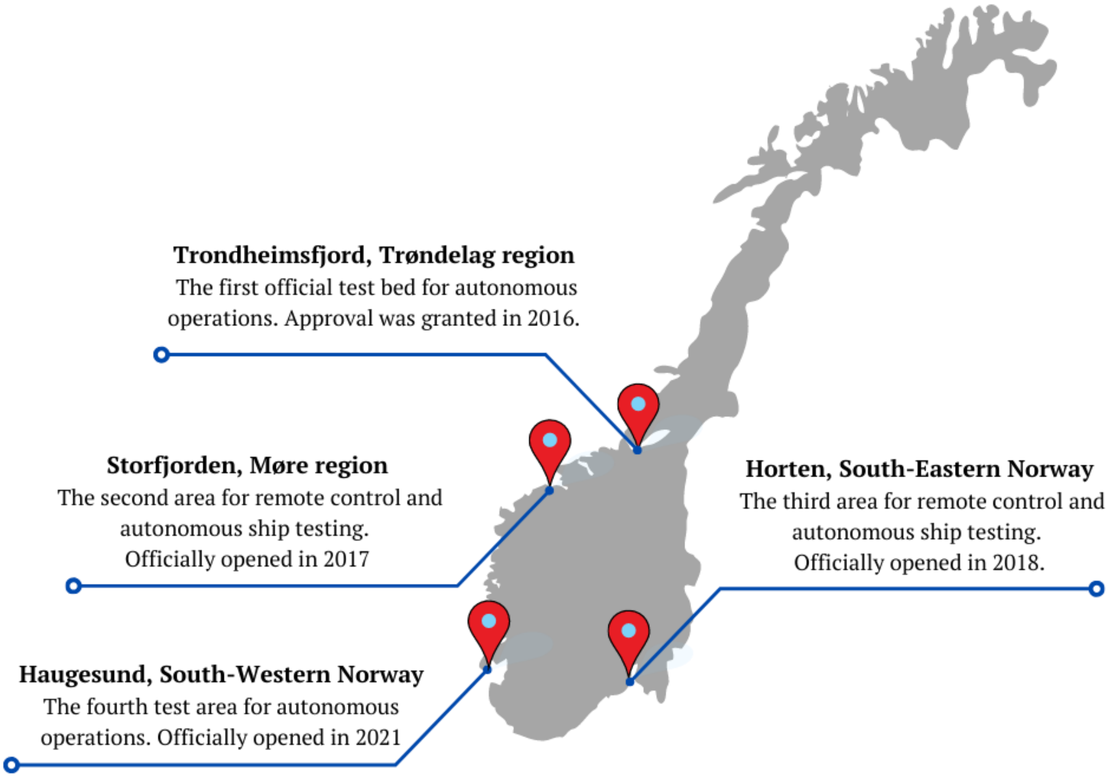


Figure 3: A visualization of the designated test areas for autonomous operations that have been approved in Norway as of May 2022 (made by the author).

Larger companies have had and still have a strong presence within the TIS. This is illustrated by the number of new projects announced and actors joining forces across sectors to utilize the technology to improve their logistic operations. Jotun (the world-leading provider of marine coatings for maritime transport) and Kongsberg Maritime joined forces to focus on problems related to biofouling in maritime transport. This resulted in the introduction of the Hull-Skater Solutions (HSS), a break-through hull cleaning solution, in Mars 2020 (Kongsberg, 2020a). "The technology aims to help shipowners steer a more profitable and sustainable path into the future" (Jotun, 2021). When Yara and Kongsberg announced building the world´s first autonomous and zero-emission ship, Yara Birkeland (Yara, 2017), another significant shift took place as commercial actors were now finding interest in the technology to reduce emissions in their supply chains. Another similar project is the development of ASKO´s two new sea drones (Kongsberg, 2020c). These three projects are considered significant milestones for the growth of sustainable maritime operations in Norway. "When large actors wish to be global leaders, is it often more power in these companies to carry out projects, both in terms of competence and financially" (Informant E). Worth noticing is that the goods-owners themselves are initiating these projects, and aims to utilize the technology to optimize their logistic operations.

To summarize, it is evident that several vital processes are taking place within the TIS, leading to new projects being announced and new actors entering the TIS to take part in the development. Today, four designated test areas have been approved for testing. With that said, entrepreneurial experimentation has been heavily dependent on large firms to bear the cost and a more substantial commitment from the public sector is needed to strengthen the function. Taking this into account, I assess the function to intermediate.

5.3.3 Market formation

For radical innovations, markets do not exist yet, and potential customers are not aware of the need for the technology or how to take advantage of it. When an innovation system develops, it can create disruptive change to existing systems (Coenen, 2010). Furthermore, the formation of markets depends on changes in user practices and institutional structures (i.e., the allocation of funding and policy instruments supporting the technology), a process in which established markets can try to slow down (Truffer & Coenen, 2012). Niche markets for special applications can therefore be a way of shielding new technology from established environments (Schot et al., 1994).

> "What we see today is more automation. Today unmanned operations are being implemented, but unmanned does not necessary mean that there is no people in the loop e.g. in a control center on land" (Informant G).

Green technology has come a long way, illustrated through electrification and the use of alternative fuels to reduce emissions and make ships more energy-efficient (Mäkitie et al., 2022). In terms of autonomous technology, expectations are first and foremost formed around implementing the technology as a support system on vessels in combination with low- or zero-emission solutions. Combining green-and autonomous technologies enable ships to be both zero-or low emission and autonomous, opening a whole new market. "When new ships are being built, that are going to last for 15-20 years, it is logical to also think about digitalization and automation" (Informant D). With that said, autonomous technology is primarily a tool in the transition to a more sustainable and efficient transport system and not the solution. "Autonomy is the tool, but not the goal" (Informant H). "Autonomous technologies and solutions have the potential of replacing humans in dull, dangerous and dirty operations, however, autonomy is not the solution, autonomy is a tool…and a tool that should be applied where it is appropriate" (Informant A).

> "Many wait to see that everything works on a technical, operational, and not to mention, regulatory level… I believe that the fact that pilot projects initiated by customers are actually being realized is a decisive milestone for others to join the development and start to look at it as a real opportunity" (Informant D)

As a result of the entrepreneurial experimentations that have, and are, taking place within the field, several segments feasible for application can be observed. The most developed market segments today is within short sea shipping, in which vessels are operating in a short predefined route from A to B, transporting freight or passengers. This has also shown to be the case for fully electric vessels e.g. ferries (Bach et al., 2020). "I believe that the reason why we see a rapid increase and interest in autonomous technology today, is that the technology first now is mature enough, and people are starting to see different application areas for it" (Informant A) "I think the potential is huge within deep-sea shipping…but I think short sea shipping is where the technological development has come the longest" (informant A). "Smaller ships that operate with high frequency, and differentiated speed can be an opportunity to make maritime transport more competitive" (Informant H).

For the ferry segments are the transport of passengers in urban waterways and cruise traffic receiving interest, visible through projects initiated by e.g. Zeabuz and Hyke. This segment is of particular interest as the size of the vessels avoids some of the obstacles related to regulation in open waters. "What we envision in urban waterways, where there is a good traffic base, is multiple small ferries operating in a network" (Informant J). "Smaller vessels, less than 15 meters, are not subject to the IMO regulation and SOLAS which is the International Convention for the Safety of Life at Sea" (Informant D). In addition, the waterways laying there as free and accessible infrastructure, in contrast to land-based infrastructure. "By using existing waterways, the infrastructure is resilient with very limited need for maintenance" (Hyke, 2022). "When you look at the map of Norway, then you'll see that the potential for passenger transport is huge" (Informant F). However, an obstacle in this segment is the human factor of passengers which can give challenges in regard to legislation and safety measures. "My assumption is that freight vessels operating in a predefined route without passengers on board will be the unquestionably easiest to do" (Informant C).

> "The market for urban mobility or urban transport is huge, again because of the megatrends of people moving to the cities, waterfront densification, and non-scalable infrastructure on the land side"(Informant J).

When it comes to freight transport, Yara Birkeland has been an important pilot project to realize the potential of green autonomous technology for maritime transport. Therefore, a significant milestone was reached when YARA Birkeland was set in operation in 2022 (Stensvold, 2022). Leading up to this milestone, several other critical processes also took place. Massterly was, for example, established in 2019 to operate the vessel (Wilhelmsen Group, 2018). The fact that this segment avoids the human factor of the passenger is most likely one of the reasons the technological development has come this far in the freight segment. "Autonomy will come gradually, and I believe we will see in on freight first because it avoids the safety problem of passengers" (Informant C). As late as May 5th this year, a new large project was announced to build a zero-emission autonomous coastal container feeder (DB Schenker, 2022). The Coast Feeder will be designed for efficient and zero-emission autonomous operations and operate between the Ekornes production site to the Port of Ålesund, Norway (Vikan, 2022b).

Besides applying the technology as a support system, the potential of using green autonomous technology to address one or several other operational challenges is evident. The partnership between Jotun and Kongsberg to develop the Hull Skater solution emphasizes this statement as the Hull-skater Solution delivers innovative, proactive, and sustainable fouling control (Kongsberg, 2020a). In addition to solving a problem related to biodiversity, a cleaner hull will also reduce friction in the water and, therefore also, reduce fuel emissions (Jotun, 2022b). "On the larger ships, 70% of the fuel emission goes to overcome friction in the water" (Informant E).

> "The Hull-Skater Solution solves two socio-technical problems in particular. It prevents unwanted species to travel from one country to another, and it reduces friction from the hull, enabling more efficient operations and reduced fuel emissions"(Informant E).

To summarize, markets are forming, especially within the short sea segment and transport of freight and passengers. However, only one project is set in operation today, and a significant maturing is needed for the technology to gain ground and disrupt the status quo of the existing system. Furthermore, the technology still has a way to go to overcome its "liability of newness" and gain social acceptance. Therefore, the function is assessed weak.

5.3.4 Influence on the direction of search

The influence on the direction of search function refers to mechanisms that influence the selection or rejection of a particular direction taken by actors (Coenen, 2010). When autonomous technology was introduced, it was interpreted as futuristic and frightening, resulting in a resistance to change in established systems. Therefore, a certain level of maturing had to take place for actors to start investing in and see entrepreneurial opportunities within the TIS. Several mechanisms can influence entrepreneurial actors' interpretation of opportunities within a TIS. This chapter aims to address some of these.

Today, the technology is slowly starting to overcome its "liability of newness", in some segments. New actors are entering the TIS, which indicates that the technology is perceived as attractive. With that said, the way autonomous technology was introduced created barriers because seafarers are highly safety-focused. This presents one of the main challenges regarding the attractiveness of the TIS. Therefore, efforts have to be placed on building trust and legitimation towards the technology developed and ensuring that sufficient safety levels are met. "If Norway is to be a leading ocean economy, the safety and welfare of workers must have priority" (Ministry of Trade, 2021a).

> "Around the time people started talking about autonomy, there was a resistance to everything new…autonomy was presented as something that was fully automated and unmanned (ref. self-driven), instead of introducing it as a support system" (Informant C).

Another mechanism influencing the interpretation of opportunities within the TIS is growth in other countries. As mentioned, the Netherlands, Belgium, Germany, and Finland are all taking part in the development, and areas for testing and piloting autonomous technology have been approved. Technological developments within the field in any of these countries will most likely initiate processes within the TIS of green autonomous technology in Norway as well. In addition, great interest from international actors to do the development phase in Norway can be observed. "Several foreign companies consider running the innovation phase in Norway because it is so favorable here" (Informant B). The impact of such entrepreneurial activities on the TIS is hard to predict, but increased entrepreneurial activity will most likely allow for new learning to take place.

Changes in landscapes (e.g. climate change or wars) can also influence the direction entrepreneurial actors take when searching for new opportunities (Bergek, Hekkert, et al., 2008). The fact that autonomous technology is highly digital presents a challenge as trust in digital technologies has to be formed on a societal level. This perception can suddenly shift if e.g. a cyber-attack or a system error were to occur. "An important thing to highlight is that there are other things than the technology and legislation that can hinder the development. War and Cyberwar, for example. Will people then become terrified of anything that is technologically advanced? " (Informant I). How situations like the one described by Informant I would potentially influence the development is hard to predict, but the consequences of such an event can affect the TIS substantially.

In addition, markets and governments also influence the direction of search function. The immense pressure on industries to participate in the green shift might result in green autonomous technologies ending up in the shade of green technologies. This concern was raised during the interviews. "I believe the shipping industry has more than enough to cope with the new environmental restrictions, so there is a good chance autonomy will have a hard time gaining attention" (Informant E). Actors tend to focus on their core activities in turbulent times; however, new standards and regulations regarding energy efficiency and sustainability force industries to transition. Shipowners have no other choice than to adapt and implement new and innovative solutions on their vessels if they want to stay competitive. The fact that autonomous technology, first and foremost, is a tool that has to be implemented in combination with green technologies to generate the most value makes it vulnerable to competing technologies. Electrification and alternative fuels have gained particular attention within the green technologies (Mäkitie et al., 2022).

> "By the end of 2026, the majority of the shipping fleet will most likely make investments to reduce CO2 emissions to comply with new IMO restrictions…If industries choose not to, then 50% of their shipping fleet will not meet with new environmental requirements" (Informant E)

To summarize, the development of green autonomous technology for maritime transport is highly influenced by external forces such as the twin transition of digitalization and the demand for more sustainable solutions in society. Adding to that, the fact that the trust and social acceptance of the technology can easily be threatened by events such as cyber-attacks or accidents. As the TIS is highly vulnerable to external forces and changes in other sectors, countries, and landscapes, I assess this function as strong.

5.3.5 Resource mobilization

Resources are necessary as a basic input to all the activities within innovation systems. The pilot projects that are taking place within the TIS today have been heavily dependent on a large firm´s willingness to invest and be the risk bearers. With that said, are resource mobilization from other sources and uncertainties in regards to the short and long-term value of the technology considered barriers. "Willingness to invest is a barrier. There are still large uncertainties in regard to what value investments in autonomous technology will have in the short and long-run" (Informant A). "The interest is there, but at the same time is there a skepticism as quite large investments are needed" (Informant A). The high cost and uncertainty related to radical innovations place an emphasis on the importance of resource mobilization from a variety of sources to not hinder innovation processes.

Several actors are requesting a stronger commitment from the government to support the development of the technology through funding and policy schemes. "There is a need for lift capacity ("løfteevne") and clarification around who should bear the cost. Enormous investments and a slightly immature market – then you start fighting" (Informant C). "To succeed the public have to take some of the risks in regard to innovation activities" (Informant I). "Norway is really bad at strategic commitments… It is only luck and skill that we will the race because there is so little money in it…other nations are allocating an enormous amount of resources" (Informant C). "We are depending on public investment to achieve the green shift" (Informant B). "Nobody has the courage to put large resources on the table before they see that the technology actually functions and that a regulatory framework is in place to support the technological developments in the field" (Informant A). "If Norway is going to be a leading nation in the field, then the public sector also has to contribute” (Informant E). With that said, several public funding and support schemes are in place today with various degrees of impact.

Examples of how public institutions can support and strengthen the TIS functionality are through infrastructures that allow for knowledge spillover and tacit knowledge, financial support, or guidance to ensure that the safety of the technology being developed is sufficient. The Norwegian Research Council, Enova, SIVA, and Innovation Norway are important institutions facilitating funding and support schemes when developing new technologies. Support schemes ensure a steady flow of funding and new competence to the field and aim to foster and strengthen entrepreneurial activities and innovation in Norway (RCN, 2022b). Within green technologies, should the Green Platform Initiative (Grønn Platform, 2022) and The Explorer (Explorer, 2022) be mentioned. The Green Initiative is a government-funded initiative meant to trigger investments in greener and more sustainable solutions. The Government then granted NOK 1 billion to the program over three years (2020-2023) for a green transition of the industrial sector (Grønn Platform, 2022). The Explorer is the official marketplace for green and sustainable technology from Norway, and part of Innovation Norway’s efforts to promote Norway as a sustainability pioneer (Explorer, 2022). The Norwegian NOX fund was also established in 2008. In addition, have public procurements been shown to be an effective tool in incentivizing the adaption of alternative fuels and battery-electric systems in the ferry segment (Mäkitie et al., 2022). “Public procurements have huge potential” (Informant F). Such market-push and market-pull mechanisms illustrate how public involvement can influence technological development within sectors.

In terms of autonomous technology, observation can be made that resources are allocated to the field through, e.g. funding schemes such as the SFI Centre for Research-based Innovation (RCN, 2022a), PILOT E (Grünfeld et al., 2020), and Innovation Contracts (Innovasjon Norge, 2022a). The SFI Center for Research-based Innovation is a funding scheme through The Research Council of Norway that aims to develop expertise in fields of importance for innovation and value creation (RCN, 2022a). Several research centers are in the works directed toward autonomous technology, e.g., SFI Smart Maritime and SFI Autoship. SFI Smart Maritime is a center for research-based innovation dedicated to improving energy efficiency and reducing harmful emissions from ships (Smart Maritime, 2022). SFI Autoship is an 8-years research-based innovation centre to develop and manage technologies, systems, and operations for safe, sustainable, secure, and cost-effective autonomous sea transport operations (SFI-Autoship, 2022).

What can be observed as an obstacle is that these funding and support program often supports either of the technologies but not both under the scheme. Actors are therefore requesting more funding and support schemes allocated towards technological developments featuring both green and autonomous technology. ”When we look at funding schemes, quite a lot are allocated to zero-emission and decarbonization of the shipping fleet, and relatively little to the autonomy and technology aspect which also can contribute!” (Informant A). “I observe that we often operate in silos. On one side, you have the energy projects; then you have autonomy on the side. However, I think it is time to unite them” (Informant A). “We would like to have more “free” resources because our role as driver are strongly linked to take initiative to new things and bring actors together” (Informant B). In other words, a wholehearted commitment from the government to allocate funding and support schemes that feature both green and autonomous technology is requested. In addition, is it a reason to believe that policy intervention utilizing property-based approaches greatly influences the TIS. In a Norwegian context, Siva is one such example that facilitates a strong regional infrastructure for innovation through business incubators, business gardens, and research and technology parks) (SIVA, 2022).

The involvement of large firms was addressed several times through the interviews: "Much of the power to transform shipping lies with the cargo owners, the freight traders, and the end customers" (Informant D). «Large cargo owners take the initiative, set requirements, and initiate projects" (Informant F). Such investments lead to institutional change, and it has become clear through this research study that large goods owners have a significant influence on the functionality of the TIS. One of the informants gave an excellent example: «The market value of Amazon is about the same as the value of all the world´s ships above 1000 gross tons. This illustrates that there is money available, and this money can be leveraged by the cargo owners" (Informant H).

I mentioned that SMEs and start-ups can have challenges in mobilizing enough resources. Applying for funding is often a complex and demanding process. Large firms, therefore, have advantages in terms of administrative and technological capabilities when applying for public R&D funding or investment support for the piloting of the technology. In addition, a natural explanation for why start-ups and smaller firms are targeting the ferry segments, in particular, can be that some of the safety requirements which apply in open waters are removed, environmental conditions are more predictable and the vessels are smaller, which can reduce cost and uncertainties in the development phase. With a lower threshold to enter and start experimenting in these segments, chances are also higher that the actors can preserve the rights to the technology and better utilize their internal competencies without being marginalized. Start-ups bring new business ideas into existence and are a good source of innovation, so the government should work to facilitate better funding for these actors and protect their technology when large firms want to join forces and develop the technology further. Zeabuz, Maritime Robotics, Hyke, and others, are setting the example, and their presence can influence other actors´ interpretations of entrepreneurial opportunities within the field.

To summarize, resource mobilization is needed to develop the technology, complementing technologies and infrastructure, and competence. Even though some funding and support schemes are already in place, the industry is requesting a stronger government commitment and funding allocated to projects featuring both green- and autonomous technology. The need for more "free" resources and to reduce uncertainties regarding who should bear the innovation risk have also been addressed. The role of large goods owners has also been addressed. Based on these findings, I assess the function as intermediate.

5.3.6 Legitimation

Legitimation can be seen as a prerequisite for forming new industries as it counteracts resistance to change (Coenen, 2010). There is a long way to go for green autonomous technology to overcome its liability of newness; however, several vital processes are taking place within the TIS today to support the process of legitimation. However, when a new technology emerges, it often relates to or competes with established TISs. The resistance to change that can evolve can slow down processes of legitimation in efforts to defend established systems (Bergek, Hekkert, et al., 2008).

Today, the technological development of green autonomous technology is one step ahead of the national frameworks that can protect it. This is one of the challenges that will be addressed.

Norway is one of the leading countries in the development and uptake of low- and zero-emission technologies in shipping (Bergek et al., 2021). The development and implementation of green technologies (e.g., battery-electric and hydrogen) in maritime transport have come longer than autonomous technology and have, therefore, also gained more legitimacy. This legitimacy has been built through experimentation with and implementing the technology, resulting in learning effects and reduced uncertainties regarding how the technology functions in practice (Mäkitie et al., 2022). Even though green- and autonomous technology are at different development stages, the two TISs support each other and legitimation within one TIS will also build legitimacy towards the technology developed within the TIS of green autonomous technology.

Norway has since 2016, through organizations such as the Norwegian Maritime Directorate, the Coastal Administration, NFAS, and the Ministry of Transport, worked close with the EU and IMO to put autonomy on the political agenda and stress the need for a regulatory framework for autonomous maritime transport (Maritime Safety Committee, 2018; NFAS, 2022; NMA, 2022a) IMO´s Maritime Safety Committee (MSC) agreed in 2017 to include Maritime Autonomous Surface Ships (MASS) on its agenda, following a proposal by a number of Member states, including Norway, to ensure that the regulatory framework for MASS keeps pace with the technological developments (IMO, 2018; Maritime Safety Committee, 2018). Norway submitted a draft of interim guidelines for MASS trials to IMO in 2018 (Maritime Safety Committee, 2018). As a result of pressure from several nations, IMO approved the first Interim Guidelines for MASS trials in June 2019 (IMO, 2019).

> ”If the demand for a new regulatory framework becomes large enough, NMA would most likely direct more resources towards developing a prescriptive regulatory framework. As of today, novel technology and new designs are approved based on the principle of demonstrating an equivalent safety level to conventional solutions. This approach is risk-analysis based and requires much time and resources from both the applicant and from NMA” (Informant D).

Today, Norway’s testing and piloting of green autonomous technology follow an alternative design process. Actors have to provide sufficient documentation that the technology and vessels meet safety measures equivalent to or higher than on conventional ships. “NMA offers an alternative design process for new innovations, not currently covered in the existing regulations. The key criteria is to document for sufficient safety” (Informant B). “The Norwegian Maritime Authority develops the regulations for Autonomy in parallel with the industrial developments and in close cooperation with the industry to ensure that the regulations are developed according to the needs” (Informant F). Different opinions can be observed regarding how well this process works in practice. While some actors demand more standardized approval processes for autonomous operations, others state that a standardized framework this early in the development phase would negatively influence the TIS and, on the contrary, hinder innovation processes. “It will be important to implement a regulatory framework, a protocol or a process to standardize legislation” (Informant A), “Most of today’s regulatory frameworks are built for larger ships in open waters” (Informant J), “The regulatory framework that exists today is written in a time in which autonomous technology was just a wild fantasy” (Informant A),

> "If the NMA was to provide a standardized, descriptive regulatory framework now it would have to be very strict, to ensure it is safe enough, and there would have been a need to adjusted it to meet new demands…The goal of a regulatory framework is hard to foresee based on two-five projects" (Informant G).

In terms of social acceptance and change in user practice, some distinct processes can influence the TIS. The twin transition of sustainability and digitalization makes the technology more acceptable, and the Norwegian population is well aware of the consequences of e.g., carbon emission is not reduced (Menon Economics, 2022). The fact that levels of autonomy have been outlined (Rødseth & Nordahl, 2018) can ease the social acceptance of autonomous technology, as a society can adapt and adjust over time. On the other side, there is a need to establish trust in complex systems as human interference when technologies reach a certain level of complexity can be challenging. "The interaction between software systems and humans is challenging" (Informant J). Moreover, communication around new technology is an important aspect of achieving social acceptance and change in user practices. "Remember that you are talking to a personnel that is extremely safety-focused, and search for comfort in what they do, in other words, are the communication around it very important" (Informant C)

> "If people would have thought it through beforehand, and told the industry that the technology would be implemented as a support/or safety system, and tested and built legitimacy around it…it would have been a better strategy than talking about self-driven vessels" (Informant C)

To summarize, while the twin transition of sustainability and digitalization are strengthening the process of legitimation, a lack of a standardized approval process for autonomous operations and uncertainties regarding social acceptance are observed as barriers. An alternative design process has been developed to ensure that the technology meets specific safety requirements. Norway is also at the forefront of the technological development, and actors are working closely with the EU to ensure that a regulatory framework will respond to industry needs. With this said, will the legitimation process take time. I assess the function to intermediate.

5.3.7 Development of positive externalities

The development of positive externalities indicates system dynamics on a functional level and refers to outcomes of investments that are hard to predict at the time of investment (Bergek, Hekkert, et al., 2008). Such outcomes become available for all actors within a TIS and can even facilitate growth in other established TIS. Positive externalities typically increase as more entrants are joining the TIS, and the formation of clusters is one example.

As mentioned, significant investments are needed in complementing infrastructures and competence. This can e.g., set processes in motion in public and private sectors to build new infrastructure, close knowledge gaps, and develop funding and support schemes to explore the technology further. For example, there is a need to upgrade port infrastructure to complement technological developments. More flexible transport systems mean that smaller ports with little activities today can be utilized. This can initiate processes in which land-based infrastructure will also be upgraded. "The ports are in the same situation as the shipping companies; they have to upgrade their infrastructure to be competitive through the energy transition" (Informant D).

> "The transition to zero-emission fuels has a large cost both related to vessel equipment, port infrastructure and the price of new fuels. If we can reduce the operating cost associated with the crew, and increase the efficiency and flexibility of the fleet, it will make the energy transition easier" (Informant D).

Specifically, automation and remotely operated industrial assets may have disruptive effects on the types of employment and competence needed in sectors. Overall changes in firm and value chain composition and the kind of jobs and competence needed may also influence the institutional setup that regulates industries. For example, can parallels be drawn to air transport in terms of international competition, regulatory frameworks, and long development- and life cycles making the transportation system less responsive to change. "A lot of the traffic control will most likely be similar to what is going on in air-transport. Timeslots or corridor principle" (Informant I). In addition, replacing existing systems with more sustainable and efficient solutions will contribute positively to reaching the targets set out in the Paris agreement, as land-based logistic operations can be moved to the sea. This also means that more jobs will be created in the maritime sectors. "There is great potential in increasing the utilization of maritime transport systems to replace trucks" (informant H). "The influence on seafarers will most likely be minimal, since many of the concepts do not replace an existing vessel, and the seafarers will in many cases be needed somewhere in the loop" (Informant G). In other words, the TIS of green autonomous technology can benefit from development in other TISs, and other TIS can benefit from development within the TIS of green autonomous technology.

Norway is one of the leading nations in the world in terms of green autonomous technologies. This gives Norway a voice globally, and Norway should use this voice to strengthen the development within the TIS. "We are well-positioned and have good collaborations with the Nordic countries, which hold many of the same challenges. Together, we have a larger voice internationally" (Informant I). Norway is actively working with the EU through programs and research partnerships like the European Green Deal and Horizon Europe (Ministry of Trade, 2021a). Horizon Europe has several blue initiatives in the works from 2021 to 2027. It is of great interest for Norwegian actors to ensure that the EU's blue programs respond to the demands and needs of Norwegian ocean industries. Also, among the Nordic countries, is Norway a driving force for several initiatives concerning the oceans, including green shipping (Ministry of Trade, 2021a).

To summarize, the development of positive externalities refers to processes resulting from an investment or action in a specific field. The TIS of green autonomous technology can take advantage of and facilitate the development of positive externalities; however, at this particular point in time, the development has not come to a point in which many positive externalities can be observed. I, therefore, assess the function as weak.

5.4 Summary and overall assessment

Maritime transport can be conceptualized as a socio-technical system in which various elements are interlinked, depending on each other, and together provide a service to the society (Bergek et al., 2021; Markard et al., 2012a).

Through the functional analysis, we have learned that the TIS of green autonomous technology consists of a mix of large firms, SMEs and start-ups, financial and regulatory institutions, and various learning networks that influence the functionality of the TIS through different processes. Knowledge development and diffusion seem to rise as more actors find the TIS attractive, and new entrants lead to more entrepreneurial experimentations and pilot projects being announced. Drivers for the development of green autonomous technology are, e.g., sustainability and digitalization, whereas the COVID-19 pandemic and the war in Ukraine can influence the functionality of the TIS negatively. Urbanization, a densification of the waterfronts, and non-scalable infrastructure on the land side are other reasons that emphasize the need for new and better transport systems.

This analysis base its findings on the assessment of the TIS at this particular time and suggest that system-building activities needed to strengthen the TIS should enhance entrepreneurial activities and allocate more resources to the field. Identifying processes leading to knowledge development and diffused within a TIS allows for identifying critical knowledge gaps, encouraging new actors to enter the TIS, and increasing the number of entrepreneurial activities. This is important for the technology to reach a sufficient level of testing and verification and eventually will legitimize the technology. In addition, uncertainties must be reduced to justify new user practices on a societal level.

The fact that various actors find interest in the technology and markets have started to be formed indicates good preconditions for new technological developments in the field. With that said, are resources mobilization, legislation, and legitimation presented as the main obstacles influencing the functionality of the TIS today. The analysis identifies that the development of green autonomous technology for maritime transport, in general, is capital intensive, complex, and demands shifts in socio-technical systems. Therefore, a more substantial commitment from the government to develop funding and support schemes supporting the development has been requested by industry actors. Public involvement through technology push and market-pull mechanisms has also effectively driven innovation processes.

In terms of legislation, an alternative design process is applied to ensure the safety of projects in the field today, and Norway is also actively involved through organizations like NFAS in putting pressure on IMO to set processes in motion to develop a standardized regulatory framework. The public and private sectors, both national and international, are encouraged to participate in this development. With that said, the need to conduct more projects is evident if a regulatory framework is to reply to grand industry challenges, and more resources, in terms of funding and support schemes, therefore should be allocated to the field to reduce some of the innovation risk involved in carrying out new projects.

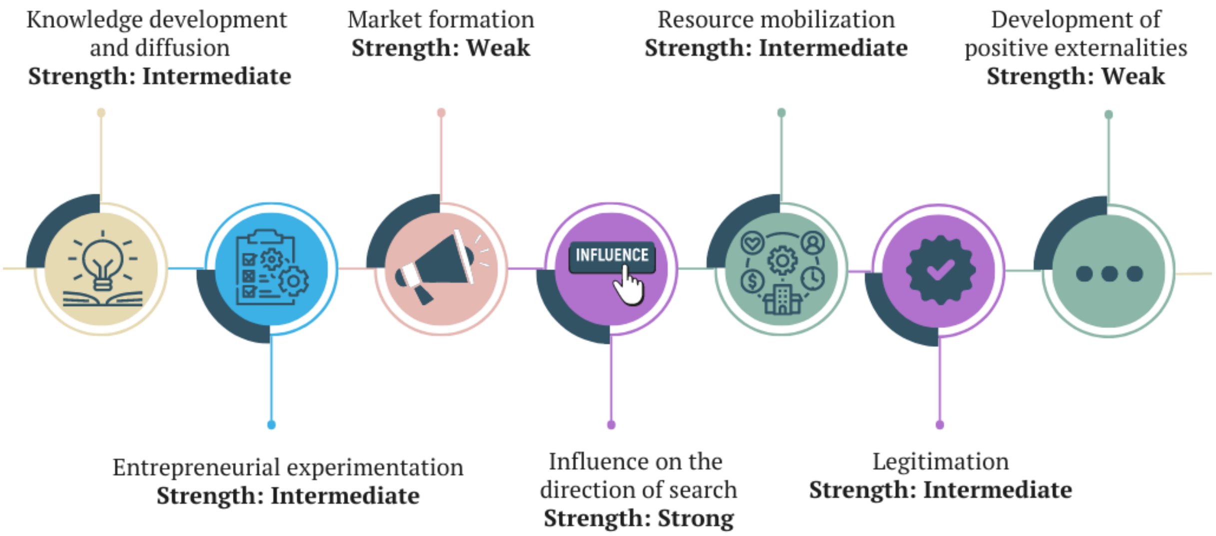


Figure 4: Assessment of functional strength. This figure summarizes the assessment of the seven functions researched in the empirical analysis.

6 Discussion

Awareness about environmental issues is generally high in Norwegian society, and digitalization and a demand for more sustainable solutions are, without doubt, causing substantial changes to maritime transport systems (Ministry of Trade, 2021a; Ministry of Transport, 2016-2017). Norway´s maritime cluster has been active in developing environmental innovations (Bach et al., 2020). As mentioned, maritime activities have resulted in a highly skilled and educated workforce in maritime sectors (Ministry of Trade, 2021a). Norway is a major ship-owning country and is among the global leaders in maritime technologies (Tenold, 2019). A more competitive, safer, and greener shipping are why autonomous technology should be implemented in future maritime transport systems (Rødseth & Nordahl, 2018). With that said, autonomy is first and foremost a tool, and autonomous solutions should be implemented in combination with green technologies to generate the most value. Fortunately, Norway is considered a leader in developing low- and zero-emission carbon technologies (Bergek et al., 2021), which presents a substantial opportunity for Norwegian actors to lead the transition.

Norway has the second-longest coastline in the world and a strong maritime cluster with a unique combination of active owners looking for new and profitable solutions and skilled seafarers with practical experience (Ministry of Trade & Energy, 2017). These are good preconditions when developing new technological solutions for future maritime transport systems, as stricter environmental requirements and a demand for sustainable solutions on a societal level are forcing industries to change. While the analysis has not gone into dept on green technologies, in particular, have autonomous technology implemented in combination with green technology been in focus. This thesis started by outlining a research question, and to conclude this research, this chapter, therefore, aims to examine and discuss key findings in the light of the research question:

> *What can the TIS of green autonomous technology teach us about the technology and the benefits of implementing it in maritime transport systems?*

6.1 Collaboration – an essential attribute

The goal of an innovation system is to develop, apply, and diffuse new technological knowledge (Hekkert et al., 2007). The technology being developed are highly competitive. Still, I have argued that a solid willingness to collaborate can be observed.

Actors generally agree that collaboration is needed to create momentum around the processes taking place within the TIS and attract the necessary resources to drive the development forward. Moreover, a common understanding has been observed that investments in, e.g., complementing infrastructure and technologies and competence are required to implement green autonomous technology in maritime transport systems on a large scale. Collaboration has been identified as an essential attribute of this process.

Cooperation through well-established models such as the triple helix model, and the tripartite collaboration between employers, allow competence to be developed close to industry needs (Ministry of Trade, 2021a; Strand & Leydesdorff, 2013).

The Norwegian government has also promoted clusters to enhance innovative capacity at the local and regional levels (Ministry of Trade, 2019), and various networks (e.g., clusters and forums) have been highlighted for their ability to develop and diffuse knowledge and produce tacit learning that is hard to copy (Bergek et al., 2005).

In addition, collaborations on an international level have also shown to be essential for knowledge development and diffusion of the technology. Actors are actively working to place autonomy on the political agenda both on a national and international level and to ensure that the result of a standardized approval process for autonomous vessels responds to industry needs (Maritime Safety Committee, 2018; NFAS, 2022).

6.2 System building activities

Several factors leading to increased entrepreneurial activities and development have been identified through the analysis in terms of system building activities. Industry actors are requesting a substantial commitment from the government to develop better funding and support schemes supporting both green and autonomous technology. In addition, collaboration is an essential attribute for knowledge spill-over and tacit learning and gaining a voice on the political agenda. Better communication around the functionality of the technology has also been emphasized regarding legitimation.

Through experimentations, social learning processes unfold in which some technologies and firms fail and others succeed (Bergek, Hekkert, et al., 2008). Even though start-ups and SMEs have shown to be particularly influential in the passenger ferry segment, I argue that investments by large firms have been crucial for technological development in green autonomous technologies in recent years. Yara Birkeland, for example, is a result of large firms initiating projects to optimize their logistic operations (Yara, 2022b). However, such projects would not be possible without government support. Maritime authorities have played a key role in establishing test areas and ensuring acceptable risk levels.

Still, it can be argued that a substantial commitment from the government to support the development of green autonomous technology is lacking, as significant investments are needed in complementing infrastructures and competence. With that said, a natural evolution seems to evolve on the technical side, and "Maritime 21" (Menon Economics, 2022), "National Transport Plan 2022-2033" (Ministry of Transport, 2020-2021), and "Blue ocean, Green Future" (Ministry of Trade, 2021a) are government reports that provide roadmaps and guidance on how to utilize new technology and knowledge in the transitioning of maritime transport systems.

Whereas large firms seem to bear the cost and innovation risk of new projects, smaller firms with limited in-house resources and capabilities may be limited as they require additional funding and support not to be marginalized. The fact that government funding and support schemes today seem to be allocated to either green- or autonomous technologies and not projects featuring both have also been addressed. Furthermore, industry actors call on the government to reduce some of the risk and cost involved in carrying out entrepreneurial activities. Adding to that, more "free funding" to conduct R&D activities has also been requested, and many informants have repeated the phrase "someone has to pay the price."

> "There is a need for more free resources"(Informant I). "In general, when it comes to autonomy, a comprehensive strategy is still not implemented" (Informant F). Requesting "a wider commitment from the government with clear targets and ambitions" (Informant B).

6.3 Feasible segments for application

Through entrepreneurial experimentation, knowledge can be collected on the functioning of the technology. When identifying feasible segments for application, it is, therefore, natural to look at the projects taking place within the field today. The most developed market segment today is short sea shipping, in which vessels are operating on a predefined route from A to B, transporting freight or passengers.

I have argued that freight transport holds the most significant potential to cut emissions as the transport of passengers adds new measures in terms of safety. Also, calculations on the number of carbon emissions that will be reduced annually have been made on some of the projects today, which provides a better interpretation of the potential long-term value of investing in green autonomous technology in the freight segment. For example, it has been calculated that ASKOs new sea drones will reduce road travel by two million kilometers and cut carbon emissions by 5000 tons annually (M. C. D. Kongsberg, 2020).

With that said, it can also be argued that the segment in which green autonomous technology is most scalable is the passenger ferry segment, with several smaller vessels operating in a network. Taking a look at the map of Norway, it is obvious that this will improve connectivity and optimize transport routes significantly. The implementation of green autonomous technology also allows for reduced crew costs, more frequent departures, and in general, a more flexible transport system that can adjust to demand (Zeabuz AS, 2022). This touch on some of the challenges in the ferry segment today.

Also, noteworthy is that the potential of using green autonomous technologies to solve other issues regarding maritime transport (e.g., biofouling) is evident. The Hull-skater solution, a revolutionary and climate-friendly hull cleaning solution developed by Jotun and Kongsberg Maritime, has been used to give an example (Jotun, 2022a; Kongsberg, 2020b).

> "In some (more susceptible) segments, new technologies might flourish using market incentives, while other (less susceptible) segments may need more fundamental changes to the existing institutional environment, such as the removal of policies supporting existing technologies" (Bergek et al., 2021).

6.4 Bottlenecks?

A lack of a standardized approval process for autonomous operations is presented as the main challenge within the TIS today (NFAS, 2022). Moreover, the need for a standardized approval process for autonomous operations in a few years is evident. Still, it can be argued that more experimentation and projects have to take place to grasp what such a regulatory framework should comprehend.

Today, green technologies (e.g., alternative fuels) hold significantly more legitimacy than autonomous technology (Bach et al., 2020; Mäkitie et al., 2022). Respectively, it is reasonable to believe that some of the learning in the TIS of green technology can be utilized in the TIS of green autonomous technology. Similarly, developments in other transport segments can also provide valuable insight into user preferences and willingness in society to adapt to new technologies.

Challenges regarding public acceptance and acceptable risk levels have also been addressed, and various levels of autonomy have been defined (Ørnulf et al., 2022). Still, it can be argued that uncertainties regarding which levels of autonomy will be implemented in maritime transport need to be reduced to gain public acceptance.

Knowledge development and diffusion around the functioning of the technology are essential in the processes of legitimation. It can therefore be argued that attention should be given to the entrepreneurial activities taking place within the four test areas that have been identified (INAS, 2022; Moderne Transport, 2021), and to place an emphasis on the diffusion of results from ongoing projects and millstones being reached. The interpretation that the technology will "replace" jobs in the maritime sector should also be addressed, as optimizing transport routes by moving traffic from road to sea, on the contrary, will generate new and safer jobs in maritime sectors.

To summarize, green autonomous technology today is in a formative phase in which some technologies and firms will fail, while others succeed (Bergek, Hekkert, et al., 2008). Transport of freight and passengers in predefined routes seems to be the most developed segment today. Still, it is high risk and cost involved in carrying out projects and new entrants should expect to meet obstacles that are capital intensive with no immediate return on investment. With that said, a strong emphasis on collaboration and a well-educated and skilled workforce are good prerequisites for a successful transition and present a competitive advantage for the Norwegian society in the transition to more sustainable maritime transport systems.

7 Conclusion

Maritime transport can be conceptualized as a socio-technical system, as transport fulfills a function in society. Today, the sector is under immense pressure to reduce its greenhouse gas emission as maritime transport accounts for 2,9 percent of carbon dioxide emissions globally, a number that is projected to increase (IMO, 2020). This research study aims to better understand processes leading to change within the TIS of green autonomous technology for maritime transport. Knowledge about the development, diffusion, and implementation of innovations within the technological field is taking place, and it can be argued that green autonomous technology will contribute with important innovations in realizing new and better transport systems.

Meanwhile, more competitive, safer, and greener shipping has been identified as reasons why autonomous ships should be part of future maritime transport systems (Rødseth & Nordahl, 2018); several challenges have also been addressed. A substantial commitment from the government is requested, support policies need to be developed closer to industry needs, and more resources should be allocated to projects featuring both green-and autonomous technology. Moreover, a standardized approval process for autonomous operations and investments in complementing infrastructure and competence will be essential for green autonomous technology to be implemented on a large scale. This presents the greatest concern among industry actors today; a lack of a standardized approval process for autonomous operations.

As revealed by the findings in the empirical analysis, the TIS of green technologies is stronger than the TIS of autonomous technology. However, autonomous technology is developing at high speed. Looking at the two TISs under one scope presents some challenges, however, the benefits of combining the two technologies to create new and better maritime transport system is evident and deserves more attention. Moreover, entrepreneurial actors' interpretation of opportunities within a TIS shapes their willingness to enter the TIS and invest in the technology. This underbuilt the need to develop and diffuse more knowledge in the field.

Several feasible areas for implementation have been discussed through the analysis. Still, it can be argued that full autonomy, with no people in the loop, is not considered realistic and certainly not profitable among industry actors today. I share this perception and want to emphasize that green autonomous technology, first and foremost, will be implemented as a support system for vessels with people on boards. Then ships will gradually build their autonomous capacity, as seen in projects today, before the personnel is moved to land and the vessels can be operated through remote control centers (RCC).

As this research study is the first of its kind in Norway, valuable information has been revealed for actors to act on. With that said, several challenges have also been identified. How actors decide to deal with these challenges will influence the interpretation of opportunities within the field, and the ability to utilize the technology to facilitate change.

7.1 Looking ahead

Understanding how changes in socio-technical systems lead to transformation as a response to societal and technological pressure is an integral part of sustainable transition studies. While this thesis investigates the TIS of green autonomous technology and the benefit of implementing such technologies in maritime transport systems, it also gives room for further research. Transport systems provide a service to society. Social acceptance of technology is therefore essential. While this thesis has addressed some aspects in this regard, a more in-depth analysis of the general interpretations in the society towards the technology would be of interest. Further research could also investigate the need for investments in new competence and upgrading of infrastructures as uncertainties regarding who should pay the cost of this transition have not been addressed. Furthermore, a concern that has not been raised is the consequence of green autonomous technologies being overlooked in the race to curb emissions and transition into more sustainable modes of operations. This gives room for further research.

8 References

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9 Appendices

Appendix A: Interview guide

Interview guide

Introduction:

A brief introduction to the thesis, myself, and the aim of the thesis.

Information on consent, anonymity, and the use of the recordings.

(x) = the person, company, organization, or institution that is being interviewed

Research topics. Questions asked in Norwegian.	
General insight: interest, past development and TIS structural components	
	1. Kan du starte med å fortelle litt om deg selv og rollen din? - Hvordan har du opparbeidet deg kompetanse på feltet?
	2. Hvilken tanker har du gjort deg rundt utviklingen og implementeringen av autonom teknologi i skipsfarten? Oppfølging:Når vekket det først interesse hos deg?
	3. Hvordan vil du forklarer den økende interessen for grønne og autonome løsninger de siste årene?
	4. Hva er x hovedaktiviteter og hvilken rolle har x ovenfor skipsfarten?
	5. Hvor stor påvirkningskraft har x til å drive/bremse utviklingen av grønne autonome løsninger for skipsfarten?
	6. Hvilke(n) rolle ønsker x å ta i den videre utviklingen av grønne autonome løsninger for skipsfarten?
Innovation and development: Pilot projects, motives, and development patterns	
	1. Når begynte x å strategisk jobbe med autonome løsninger for skipsfarten? a. Har dere noen pilotprosjekter å vise til? b. Hva var utfallet av disse prosjektene?
	2. Er x per dags dato involvert i noen pilotprosjekter som omhandler autonome løsninger for skipsfarten? a. Hva er motivet for å delta i slike prosjekter? b. Hvilke andre aktører er involvert?
	3. Hvem anser du som de mest innflytelsesrike aktørene i innovasjonssystemet?
	4. Hvordan opplever du viljen til samarbeid på tvers av sektorer, og mellom aktører? Oppfølging: Hvilke synergier er verdt å nevne?
	5. Hvilke finansielle støtteordninger benytter x for å drive med testing og utvikling av autonom teknologi? a. Hvor kommer støtten fra? b. Er den avgjørende for at x skal kunne drive med denne typen arbeid?
	6. I hvor stor grad opplever du at virkemiddelapparatet og finansielle støtteordninger er tilpasset alle bedrifter, store som små?

	a. Hvilke begrensinger finnes? b. Hvordan påvirker det markedet?
Business opportunities and application: key drivers and barriers	
	1. Basert på kunnskapen vi sitter på i dag, I hvilken del av skipsnæringen tror du autonomisering vil ha størst nytteverdi for samfunnet generelt?
	2. Hvilken regionale, nasjonale og internasjonale nettverk anser du som de største driverne av autonome og grønne løsninger for skipsfarten?
	3. Hvordan opplever du investeringsviljen og interessen i verdikjeden til å omstille seg fra en ganske tung tradisjonell næring til å nå ta i bruk ny teknologi? a. Hvem skal ta kostnaden?
	4. Hvilke forventninger har x til markedsutviklingen fremover? Oppfølging: I Norge/internasjonalt?
	5. Hva er den største usikkerheten i markedet akkurat nå? a. Hvordan påvirker det utviklingen og implementeringen av grønn autonom teknologi? b.. Hva bunner usikkerheten i?
Regulations: legitimacy and regulatory frameworks	
	1. Hvilke lovverk og reguleringer påvirker skipsfarten i dag? Oppfølging: Er det tilpasset bruk, behov og krav?
	2. Hvilke regelverk og godkjenningsprosesser berører pilotprosjekter i dag?
	2. På hvilke områder tror du Norge kan være med å drive frem et internasjonalt lovverk som tar for seg bruken av autonomi i skipsfarten?
	3. Er det noen konkrete virkemidler eller politiske føringer som mangler nasjonalt for at Norge skal kunne styrke posisjonen sin innenfor feltet?
	5. Hvilke grad av autonomi tror du er mest realistisk å implementere i dag? a. Tror du vi noen gang vil se full autonomi i skipsfarten? Begrunn svaret.
Expectations: market prospects and overall TIS functionality	
	1. Hvilke andre områder enn selve teknologien må utvikles, omstilles og tilrettelegges for skal autonome løsninger kunne anvendes? Oppfølging. F.eks infrastrukturer/transportsystemer/støttesystem/kompetanse.
	2. Hvilken rolle spiller staten i omstillingen til en grønnere autonom skipsflåte? a. Er satsningen stor nok nasjonalt? b. Blir det bevilget nok penger?
	3. Hvordan opplever du holdningen til autonom teknologi i samfunnet generelt?
	4. Er det stort nok søkelys på å utdanne kompetente fagfolk innenfor feltet?
	5. Den norske regjeringen har ambisjoner når det kommer til bærekraftig omstilling. I hvor stor grad tror du autonomi vil spille en nøkkelrolle her?
Final remarks	
	Er det noe mer du vil tilføye før vi avslutter?
	Er det greit at jeg tar kontakt for et oppfølgingsintervju og evt. andre avklaringer?

Takk for at du deltok!

Appendix B: Consent Form

Vil du delta i forskningsprosjektet

Grønn Autonom Skipsfart?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt Grønn Autonom Skipsfart hvor formålet er å se nærmere på innovasjon og utvikling av autonom teknologi innenfor skipsfarten, og kartlegge strukturer og funksjoner innenfor feltet.

Formål

Formålet med prosjektet er å gjennomføre en teknologisk innovasjonssystem (TIS) analyse for å kartlegge strukturer og funksjoner innenfor skipsfarten med fokus på innovasjon og utvikling av autonom teknologi og nye grønne løsninger. Funksjonsanalysen er den som på mange måter gir grunnlag for konklusjon og anbefalinger ut ifra analysen som er gjort.

Prosjektet er en masteroppgave og markerer slutten på en to-årig master i Innovasjon, Entreprenørskap og Samfunn. Masteroppgaven kvalifiserer til 30 studiepoeng og det er satt av et semester (i underkant av 5 måneder)til å gjennomføre prosjektet. Frist for innlevering er 18. Mai.

Hvem er ansvarlig for forskningsprosjektet?

Masteroppgaven er skrevet for NTNU, og det er Markus Steen i SINTEF Digital som er veileder.

Hvorfor får du spørsmål om å delta?

For å gi tyngde og legitimitet til prosjektet vil jeg over de neste månedene kontakte et knippe bedrifter, relevante aktører og organisasjoner som jeg mener har relevans for prosjektet. Dette for å innhente data, tilegne meg kunnskap, og få relevant innsikt i bransjen.

Hva innebærer det for deg å delta?

Metode for innsamling av data. Det er i hovedsak lagt opp til et førstegangsintervju og et oppfølgingsintervju, samt ytterligere utgreiing og avklaring av opplysninger per e-post. Deltakelsen vil foregå digitalt. Dataen som samles inn, vil bli lagret elektronisk gjennom notat og/eller via lyd-/video opptak. Uttalelser og direkte sitat vil bli sendt for godkjenning før det brukes i prosjektet.

Det er frivillig å delta

Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger

Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

- *I første omgang vil jeg, Jenny Tomasgard, og hovedveileder Markus Steen ha tilgang.*
- *Videre vil eventuelle biveiledere ved NTNU og korrekturlesere ha tilgang*
- *Tiltak som vil sikre at ingen uvedkommende får tilgang til personopplysningene er*
    - *«Navnet og kontaktopplysningene dine vil bli erstattet med en kode som lagres på egen navneliste adskilt fra øvrige data»,*
    - *datamaterialet vil lagres på en ekstern server og ikke på personlige eiendeler*

Som standard vil ikke deltakere kunne gjenkjennes i publikasjon utover at bedrift/aktør/organisasjon i noen tilfeller vil bli nevnt. Ved noen tilfeller vil deltakere kunne knyttes til en bedrift/ aktør/ organisasjon, basert på deres involvering i prosjektet, eller kompetansen og erfaringene de sitter på. Dette vil i så fall avklares på forhånd og godkjennes av de det måtte gjelde.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?

Opplysningene slettes når prosjektet avsluttes/oppgaven er levert, noe som etter planen er *Mai 2022.*

Dine rettigheter

Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke personopplysninger som er registrert om deg, og å få utlevert en kopi av opplysningene,
- å få rettet personopplysninger om deg,
- å få slettet personopplysninger om deg, og
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?

Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra *NTNU* har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Hvor kan jeg finne ut mer?

Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- *Prosjektveileder Markus Steen E-post: markus.steen@ntnu.no*

- Vårt personvernombud: *Thomas Helgesen. E-post: thomas.helgesen@ntnu.no*

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen,

Markus Steen (Forsker/veileder)/

Jenny Tomasgard (Student)

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet *Grønn Autonom Skipsfart*, og har fått anledning til å stille spørsmål. Jeg samtykker til:

- ☐ *å delta i prosjektet gjennom intervju, spørreskjema og/eller oppfølging per e-post.*
- ☐ *at intervjuer blir tatt opp på lyd/video før det blir anonymisert og transkribert.*
- ☐ *at Jenny M. Tomasgard kan bruke opplysninger jeg oppgir i prosjektet*

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

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(Signert av prosjektdeltaker, dato)

Appendix C: Overview of selected documents for analysis

Document type	Document Name	Publisher	Year of publication
White paper	Meld. St. 33 (2016–2017) Report to the Storting: National Transport Plan 2018–2029	The Norwegian Government	2016
Strategy	Meld. St. 41. Klimastrategi for 2030 – norsk omstilling i europeisk samarbeid. Melding til stortinget	The Norwegian Government	2016-2017
Corporate release	YARA and KONGSBERG enter into partnership to build world's first autonomous and zero emissions ship	Yara	2017
Press release	Interim guidelines for mass trials.	IMO	2018
Press release	Wilhelmsen and KONGSBERG establish world's first autonomous shipping company	Wilhelmsen Group	2018
Strategy proposal	Regulatory scoping exercise for the use of maritime autonomous surface ships (mass)	Norway and BIMC, Maritime Safety Committee	2018
Report	Definition of autonomy levels for merchant ships, Report from NFAS, Norwegian Forum for Autonomous Ships, 2017-08-04	Rødseth & Nordahl	2018
Action plan	The Government's action plan for green shipping	The Norwegian Government	2019
Report	STRIA Roadmap on Connected and Automated Transport: Road, Rail and Waterborne	Mayer et al	2019
Report	Greening the Fleet: A technological innovation system (TIS) analysis of hydrogen, battery electric, liquefied biogas, and biodiesel in the maritime sector	Steen et al	2019
Book	Norwegian Shipping in the 20th Century: Norway's Successful Navigation of the World's Most Global Industry	Tenold	2019
Scientific paper	Implementing maritime battery-electric and hydrogen solutions: A technological innovation system analysis..	Bach et al	2020
Report	International Convention for the Prevention of Pollution from Ships	IMO	2020

	(MARPOL). International Maritime Organization		
Press release	Jotun and Kongsberg partnership delivers innovative, proactive and sustainable fouling control	Kongsberg	2020
Press release	Kongsberg Maritime and Massterly to equip and operate two zero-emission autonomous vessels for ASKO	Kongsberg	2020
Report	Greener and smarter? Transformations in five Norwegian industrial sectors	Mäkitie et al	2020
Action plan	Zero emissions in 2050. Norwegian Shipowners Association	Norwegian Shipowner Association	2020
Report	Meld. St. 20. Nasjonal transportplan 2022-2033. Melding til stortinget	The Norwegian Government	2020-2021
Scientific paper	Sustainability transitions in coastal shipping: The role of regime segmentation	Bergek et al	2021
Press release	Torghatten satser millioner på førerløse miniferger	Horntvedt	2021
Press release	Outcome of the regulatory scoping exercise for the use of maritime autonomous surface ships (mass)	IMO	2021
Report	Maritime Forecast to 2050	DNV	2021
Report	Blue Ocean, Green Future	The Norwegian Government	2021
News Article	Nytt og unikt testområde for autonome fartøy	Moderne Transport	2021
Scientific paper	Norwegian ship-owners' adoption of alternative fuels	Mäkitie et al	2022
Action plan	Maritime21-strategi	Menon Economics	2022
New Article	Yara Birkeland. Første tur med last for Yara Birkeland	Stensvold, Teknisk Ukeblad	2022
Report	Grønn Maritime 2022 - TEKNOLOGI, UTSLIPP, VERDISKAPING OG SYSSELSETTING	Haugland et al	2022

Press release	DB Schenker plans to operate a zero-emission autonomous coastal container feeder for Ekornes ASA in Norway	DB Schenker	2022
New article	Zero-emission Autonomous Coastal Container Feeder for Ekornes in Norway	Vikan	2022

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