University of South-Eastern Norway

A Case Study of the Maritime testbeds in Norway

Learning and collaboration between the Norwegian testbeds for autonomous vessels

Candidate name: Anders Songedal

University of South-Eastern Norway
Faculty of Technology, Natural Sciences and Maritime Sciences

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Abstract

The development of testbeds has been increased significantly over the last decade in many various project and business areas. During a period between 2016 and 2021 four different maritime testbeds areas was established with the permission from the Norwegian authorities, Norwegian Maritime Authority and Norwegian Coastal Administration. Many industries have prevalent enthusiasm to commence research for new knowledges and especially autonomous technologies. With a testbed area, a commonality of developers could in undisruptive manner test their technology in real life testbeds, that gives a comprehensive research opportunity to collect data and information and collaborate with other developers in the process. Although the designs of the testbeds were developed to accommodate autonomous ships and technology can testbeds be applied to develop new technologies for conventional ships for improving the critical crew activities, ensure safer shipping and increase the emissions and operation efficiency.

This thesis has collected data from 14 anonymous interviews with selected professional persons in the different testbeds, Norwegian Authorities, clusters, and interest organizations. The target is to decide what are the barriers and drivers internal in each testbed, lessons learned and how the testbeds has collaborated and learning with other testbeds and if the testbeds is susceptible for a learning commonality.

Finally, the results given in this thesis can give the testbeds owners and third-part equipment developers an analysis about the challenges and opportunities the overall testbeds have and how to avoid them.

Keywords:

Autonomous technologies, testbeds, learning, collaboration, lessons learned, driver and barriers, living labs.

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Introduction

The challenge

The Norwegian government is urging the country to take advantage of the opportunities presented by the green shift. This means adopting a more environmentally friendly, intelligent, and green innovative approaches. To meet the climate commitments, Norway must make cost-effective changes, and the renewal of its shipping industry is a crucial aspect of this transition. The Norwegian Environment Agency is working to create new solutions for Norway's maritime industry to ensure this transition is successful (Norwegian Environment Agency, 2019).

This announcement is the background for the Norwegian Maritime Authority announcement in 2015 that they would facilitate the development of unmanned ships in Norway (Norwegian Maritime Authority, 2015). And The Norwegian Coastal Administration wanted to participate in projects related to testing technologies, green innovation and operations for autonomous vessels and launched the opportunity to establish a test arena in the National Transport Plan 2018-2029. (NTP, 2017). (The test arena will be referred as Testbed from now). “Green innovation” has become a keyword and is being incessantly brought up as a topic to reduce the environmental impact of emissions by the goals given by IMO in 2008. (IMO, 2023).

The industry has set goals to reduce emissions, but more technology and solutions are necessary throughout the value chain. Ship owners are seeking affordable and sustainable options for their vessels, while also considering market factors such as profitability and survival (Stopford, 2009). Innovators and developers require a space to test and enhance their solutions in a real environment to create cost-effective and fully automated systems or designs (Langemyr, 2017).

A testbed is a joint agreement between different parties about a common intention to cooperate and facilitate the testing of new concepts and full-scale programs related to new technology and autonomous vessels in a real-life controlled area and real-life environment (NESTA, 2019). This has resulted in a consensus to increase the technological aspect and to find new methods with the help of technology to decrease environmental emissions

throughout every part of technology, especially automation and human behavior (Norwegian Maritime Authority, 2017) which is relevant for the maritime industry.

The Coastal Administration in Norway wanted a survey on the four maritime testbeds to gather information on their current status, factors promoting activities, the extent of collaboration, and the number/types of projects in each. An important clarification is that this thesis will focus on learning since adequate learning in and between testbeds is an important success factor for achieving the government's national objectives (Oliver, 2020). Little information is available to determine if learning occurs and how.

Learning is the acquisition of knowledge or skills through experience, practice, study or being taught (Svartdal, 2022). With a good learning practice in and between testbeds will be an important success factor in achieving the government's national objectives (Dodgson, 1993). For learning is a combination of experience and collaboration (Morris, 2020).

This thesis will explore the design and motivation in such testbeds where innovators and developers can research and test their solutions. And the presents insights of experiences, lessons learned, learning and collaboration across testbeds will be presented. Additionally, the thesis examines the drivers and barriers for testbeds as an organization. Finally, how can the learning be improved between the testbeds. These research questions have been produced.

First research question (RQ1) is as follow:

What is today’s situation with the Norwegian testbeds regarding design, motivation, lessons learned, collaboration and learning (between testbeds) expressed in the testbeds today?

Second research question (RQ2) is a follow:

What are the most significant drivers and barriers today for the testbeds and their impact for the further development of the testbeds?

Third research question (RQ3) is a follow:

How can the learning be improved between the testbeds?

Before collecting the data, certain assumptions were made. The primary assumption was that the testbeds were organized facilities or organizations in a cluster, with a defined business plan and model. Additionally, since many of the testbeds were established in

2016/2017, it was assumed that they would have information readily available on the topics relevant to this thesis.

Impact of the challenge

The testbeds have potential to reduce the environmental impact and promote innovation and develop solutions if they are operated efficiently (NESTA, 2019). This corresponds well with the plans of the Norwegian authorities. They want to increase the use of new technology and research methods that contribute to easier and safer transport with lower emissions. Not only to drive innovation, but they will ensure a robust and up-to-date regulatory framework, including the use of regulatory sandboxes, in areas that are considered technologically promising, as well as an active influence on European and international regulatory development. In addition, they will make it attractive to use Norway as an arena for testing new technological solutions in the transport sector, including autonomous and zero- and low-emission vehicles at sea. The way they will do that is to facilitate appropriate research, development, and innovation (Ministry of transport, 2021, p. 12). They continue: Regulatory *sandboxes* provide room to allow testing of new technology to test out, learn and fail – but in controlled, clarified forms and under a defined supervisory regime. Learning from regulatory sandboxes can also contribute to the design of better regulations at a later stage (Ministry of transport, 2021, p. 58). This concept of sandboxes fits well with testbeds. The difference between sandboxes and testbeds is the degree of real-life environment (NESTA, 2019). The purpose of the innovation sandbox is to provide a *virtual space* where developers can experiment with their new ideas. They can test out different features, ask others for feedback, and get suggestions from potential buyers or users. It's a safe environment to explore and improve their innovations (Ribiere & Tuggle, 2010). Therefore, testbeds have an environmental impact and a commercial impact on the Norwegian industry.

Goal of the thesis

Unfortunately, there are few reports or research on maritime testbeds. There is a lack of public information that follow up on whether the various testbeds have reached their benchmarks, the current status and the progress in the testbeds. Also limited information is available regarding the specific actions, learning and procedures that occur within the testbeds. It is also important to remember that these testbeds are not separate organizations. They are a joint collaborative consists of various partners. This thesis wants to clarify the

impacts testbeds have. By survey the difference structures, drivers and barriers, and document their experience regarding the research questions will this thesis increase the testbed empiric.

The goals of this thesis are to explore the topic stated in the research questions and answering the research questions in a satisfactory manner. This thesis aims to utilize these topics with relevant theory and determine if the testbeds benchmarking goals have been reached. The testbeds drivers and barriers will be addressed, whereas this thesis will focus on discussing the barriers. Many barriers are likely to be overcome when identified and categorized, and it is important to be clear that this is an ongoing project that can still be improved (Siedlok & Hibbert, 2014). By identifying the drivers and barriers, it can assist the testbed organizers, practitioners, and other interested parties in comprehending the challenges and resolutions of operating a testbed in Norway (Walker et al., 2008).

Another goal of this thesis is to get an overview of the learning situation. The problem with not having enough knowledge about learning is that it becomes challenging for testbeds to work effectively together, and little is created together and transferred. Learning and knowledge are closely linked (Mitchell, 1997), (Glaser, 1983), (Polanyi, 2000). When we learn, we acquire either explicit or tacit knowledge (Polanyi, 2000). The first is pronounced and clear knowledge that are conscious and have also formalized. It is often easily accessible, while tacit knowledge, on the other hand, is more difficult to explain and reproduce. Tacit knowledge is ‘hidden’ knowledge (Polanyi, 2000). And to understand the learning aspects in today's competitive markets, organizations need to be innovative and adaptable to changes in external operating conditions. This is due to technological advancements, globalization, and the internationalization of markets. Therefore, it is crucial for survival in the current business landscape (Prange, 1997). And understand the learning situation, the dynamics found in the testbeds, i.e., how the testbed is adjusted, changed and improved, and understand how flexible the testbeds are (DiMattia, 1998).

Learning is crucial in the world of innovation. Innovation involves using acquired knowledge to bring about novel changes within an organization. Although learning does not necessarily result in new developments, it may involve revisiting previous practices or maintaining current ones because they are reasonable (Jacobsen, 2015). And especially in the *process innovation* that deals with technological innovations that are relevant to the testbeds (Damapour, 2012). And to what degree are the testbeds collaborating and sharing knowledge. One can pinpoint the obstacles hindering its progress by analyzing the challenges and gaining

insights from each testbed. This enables the identification of more practical approaches to achieve the testbed's objectives while also assisting organizers in determining where to concentrate their efforts to create an effective design.

Maritime Testbeds in Norway

Trondheimsfjorden

The first official testbed in Norway for autonomous ships and underwater vessels, Trondheimsfjorden was agreed between the Norwegian Maritime Directorate, The Coastal Administration and the initiators as a testbed in autumn of 2016 (TESTSITEtrd, 2016). SINTEF is today the organization with overall responsibility for the testbed. The technology ecosystem in Trondheim sought to establish a shared area dedicated to the development of innovation and technology. Trondheimsfjorden was chosen as a suitable area to be a living lab for its calm fjords and harbors, with open water and relatively low maritime traffic, and it is a safe area to test out new technology (SINTEF, 2016).

Partners in the testbed: The Norwegian Coastal Administration, the Norwegian Maritime Directorate, Maritime Robotics AS, Kongsberg Maritime AS, Kongsberg Seatex AS, NTNU, SINTEF, Zeabuz AS, Maritime Robotics, Port of Trondheim.

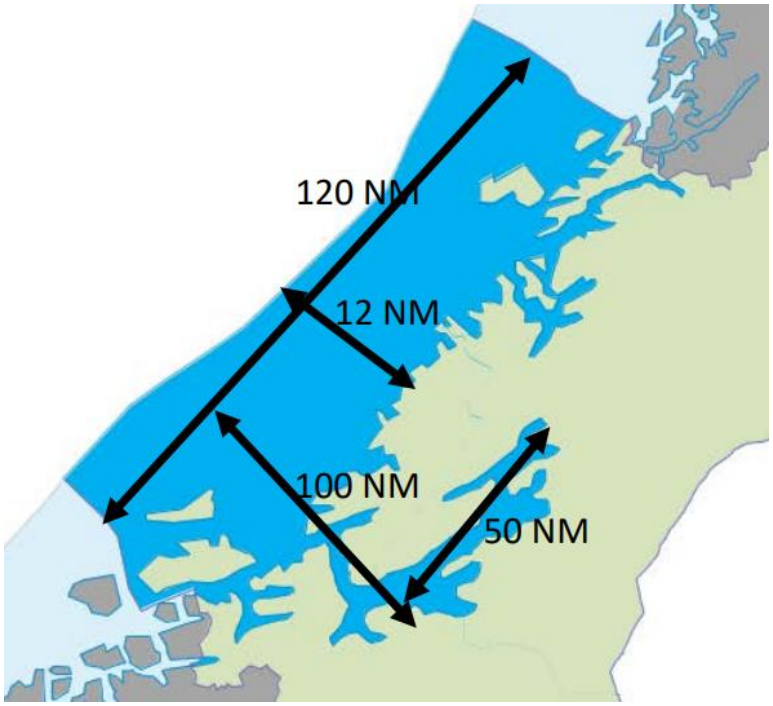

Figure 1: Trondheim testbed area. (Fjørtoft 2019)

Storfjorden

Establish in 2017, the testbed aims to facilitate testing new concepts and full-scale programs related to autonomous vessels in the Storfjorden on Sunnmøre and adjacent fjord areas in Møre and Romsdal (Stensvold,2017). Currently operated by NTNU Ålesund. Storfjorden has several relevant ferry routes that may be well suited to test and develop sensor technology and control systems necessary to develop a greater degree of autonomy in ships. In addition, there are several fish farming systems in the area and the associated sea transport that the fish framing requires. Equally important is proximity to research and educational institutions such as NTNU and SINTEF. Lastly, Storfjorden is an active arena for sea trials for newly built and converted ships and is close to several of Norway's largest shipyards (Emblem,2017).

Partners in the test bed: GCE Blue Maritime, The Norwegian Coastal Administration, the Norwegian Maritime Directorate, Rolls-Royce Marine AS, Vard Group AS, Ulstein Group ASA, Fiskerstrand Verft AS, Skipsteknisk AS, Kleven Maritime AS, Havyard Group ASA, Inmarsat Solutions AS, Ålesundregionens Havnevesen, Stranda Hamnevesen KF, Offshore Simulator Centre AS, Havila Shipping ASA, Fjord 1 ASA and NTNU.

Figure 2: Storfjorden testbed area, (Emblem, 2017).

Horten

The University of Southeast Norway (USN) is a key research player in Norway within autonomous systems and collaborates with industry on autonomous solutions for sea, road, air, rail, and industrial processes (USN,2018). Around 2017, the university took the initiative to establish a testbed, under the Autostrip project, where companies, students and researchers get access to the necessary infrastructure and knowledge to test everything from sensors, subsystems and navigation algorithms to vessels and ships. Everything is assisted and practically arranged by USN in close cooperation with the Norwegian industry (Larsen,2018).

Autumn of 2018, the university in southeast Norway opened a testbed for autonomous vessels at sea. The university has long collaborated with, among other things, Yara and the defense research institute on such vessels. The testbed that was opened in Horten is unique because it is open to anyone who wants to test technical solutions. Senior Advisor Paal Aamaas said this about the testbeds to local news. "*Autonomy is an important area of focus for us (University of Southeast Norway). Such a focus area is a very clearly stated desire from the maritime industry. We then want to facilitate closer collaboration on such projects where we can do research together. That's what it's all about for us, bringing out new knowledge about autonomy and passing this on to students and the industry*." (NRK, 2018, 3:50).

Partners in the testbed: The Norwegian Coastal Administration, the Norwegian Maritime Directorate, Kongsberg Maritime AS, the Norwegian Defense Research Institute, DNV-GL, Horten Municipality, and the University of Southeast Norway.

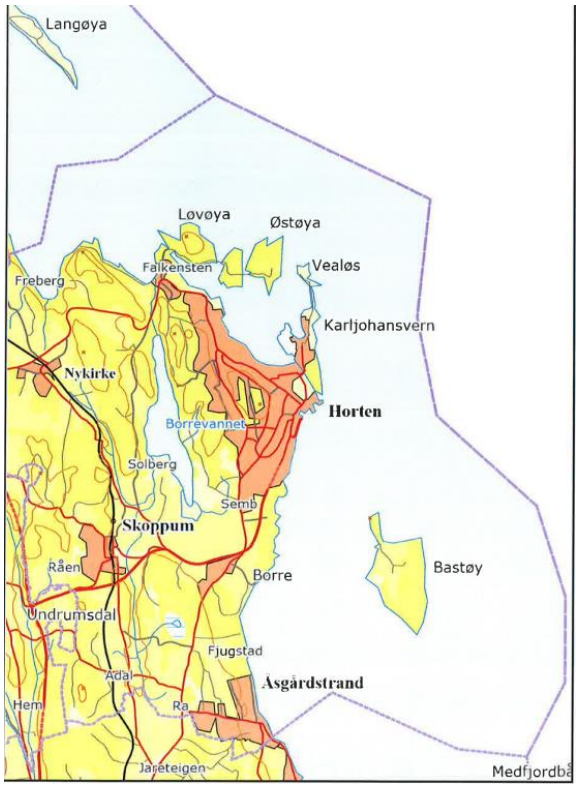

Figure 3: Horten Testbed area. (Horten, 2017)

Haugalandet

The latest testbed in the sea area in Sletta, Smedasundet and Karmsundet, which is also known as Haugalandet, established in 2021 (Norwegian Costal Administration, 2021).

The Norwegian Maritime Directorate and the Norwegian Coastal Administration have approved the new national testbed. There are 19 partners behind the establishment, where the goal is to promote new technologies at sea. Maritime CleanTech led the work to get the testbed established. The testbed, together with the other test areas in Norway, will contribute to Norwegian industry taking a leading position in solutions for autonomous operations in the maritime sector (Norwegian Maritime Authority, 2021). Currently Haugesund Municipality is the operator.

Partners in the testbed: Haugesund Municipality, Karmøy Municipality, Karmsund Havn, Kopervik Havn, Høgskulen på Vestlandet, NORCE, Deep Ocean, Massterly, Zeabuz, Marine Energy Test Centre, Simsea Real Operations, Reach Subsea, SEAM, Brødrene Aa, Kolumbus, ITS Norway, Haugesund fire service, Sustainable Energy catapult center and NCE Maritime CleanTech.

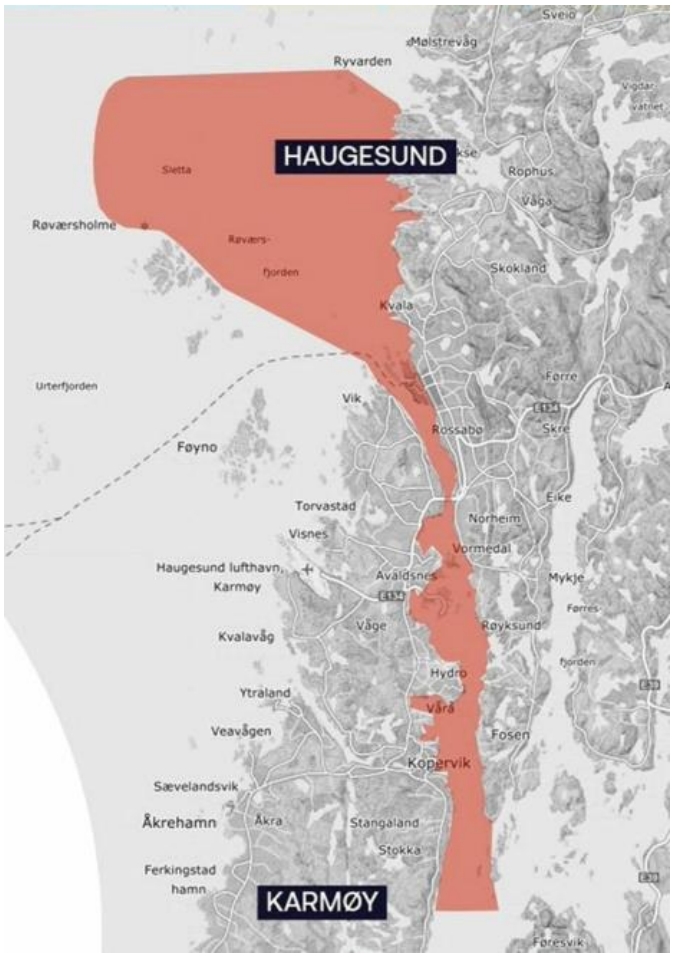

Figure 4: Haugalandet testbed area (Norwegian Costal Administration, 2017).

Literature review

Goals for the review

With this literature review the purpose is to explore the research problem in more depth and detail, explain research methods that have been used in related research and to explain the relevant theory for solving the research problem. The chapter will go through essential definitions and theories to understand the rest of this thesis. Included in this chapter are the definitions explaining the key terms and description of theoretical perspectives that have influenced how the data has been found through the work with this thesis.

Method for finding and selecting literature

Ladder of abstraction (Hayakawa & Hayakawa, 1990) was used as initial starting point for selecting literature and methods. The ladder of abstraction is a helpful tool that allows us to approach our search for literature and methods in a strategic manner while also maintaining balance in our findings. Essentially, the ladder of abstraction categorizes our findings by placing abstract concepts, theories, and ideas at the top of the ladder, while specific examples, data, and objects are at the bottom. For instance, when searching for literature related to testbeds, the search began by reviewing abstract reports and journals that presented general concepts. Once a solid understanding of the abstract literature was completed, the focus shifted to concrete literature such as guidelines and procedural handbooks for testbeds.

Reviewed literature

Testbed theory

A testbed (also referred as ‘test bed’ in some research articles) is a platform for trialling development projects. In general, testbeds involve transparent, accurate, and replicable test of innovative solutions, scientific theories, and new technologies (IALA, 2016).

Real-world testbeds are defined by Vinnova:
“*Controlled or bounded environments for testing innovation in real-world or close to real-world conditions in the manner (or close to the manner) in which they will be used or operated*” (Vinnova, 2018).

Several testbeds are already in around the globe, trialing autonomous vehicles, e-navigation, smart cities, and health technology (NESTA, 2019). This thesis will focus on the maritime testbed concepts in Norway. In addition, there are increasing number of testbeds that are under development (NESTA, 2019). Testbeds allows developers in an early stage to assess and identify the new system operational usability, functionality, identification of weaknesses, areas of enhancements and improvements, and the socio-technical impact for the end-user/costumer. Preferably, equipment development as part of testbeds should be based on the human-centered process design, which means that any operational usability problems are detected early on. Testbeds should be unrestricted by current architecture, procedures, or data structures. It recommended that testbeds should be conducted in a controlled environment. Testing new solutions does not adversely affect real-life situations and maintains maritime safety. Conclusions that can be drawn from a project in a testbed can vary in many aspects, such as risk, feasibility, usability, and functionality. The organizers decide on the design, accessibility, self-determination, and infrastructure of the testbed (IALA, 2016).

The Swedish Innovation Agency, Vinnova, has categorised testbeds into three levels, Level 1 – laboratories, Level 2 – Constructed/simulated environments, Level 3 – Real-world environments. Which each level categorising different use of testbeds (Vinnova, 2018). This thesis will focus on Level 3 – Real-world environments.

Real-world testbeds overlapping with other innovation testing tools. Experimentation and testing tools vary in two main forms. First, they differ according to the extent of control in the environment in which they perform. Laboratories try to control the environment in which experimentation and testing occur, decreasing the number of variables that might interrupt the outcome. Other technologies and solutions can only be tested in real-world environments, in which cases real-world testbeds might be more appropriate. Second, these tools vary according to the relevant phase of the innovation process (NESTA,2019). Some of these tools, such as living labs, tend to be designed to create new ideas (Bulkeley et al., 2019). Demonstrators and proving ground are used for technologies which are near completion and soon ready the market, with proven or near-proven technology such as use cases (NESTA, 2019).

The figure below shows the 3 different levels and additional innovations testing tools. On the x-axes is the innovation stage showed, and on the y-axes is the amount of control in the testing environment.

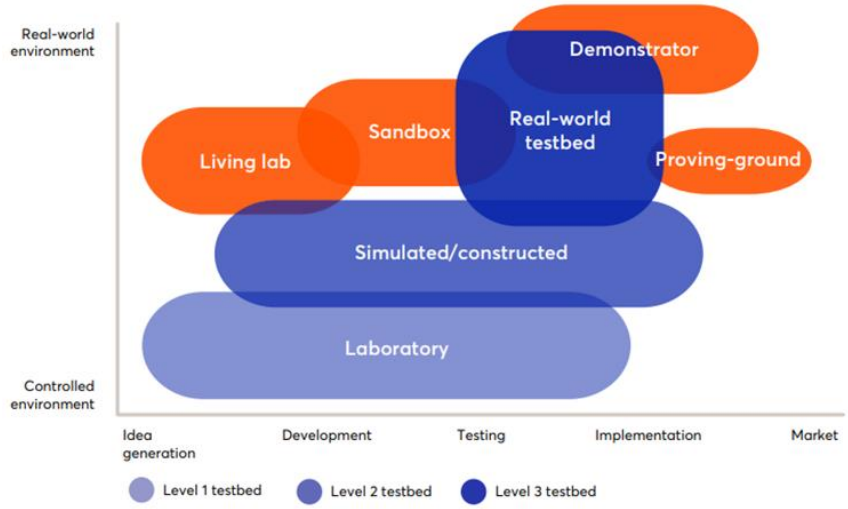

Figure 5: A spectrum of testbeds as characterized by Nesta (NESTA, 2019, p. 16).

There are few published reports on drivers and barriers for maritime testbeds. But in 2021, IMPELLO, a consultant firm, got an assignment from Trondheim municipality. The Trondheim region had a project that centred on self-driving transportation and autonomy (IMPELLO, 2020, p. 6). They explored the benefits of having a testbed for the local actors. The benefits they found were increased collaboration, attracting capital and resources for innovation, reduced risk in the development process, promoting of the local area, improving public services through regulatory systems, maximizing the commercial potential of local research, having a framework for innovation policy, shorter research cycles, highlight the export potential and to identify system barriers (IMPELLO, 2020, p. 11).

IMPELLO has carefully selected a set of success criteria from various sources such as literature and interviews to ensure that testbeds achieve their intended goals. Please note that this list is not comprehensive, and each testbed may have unique requirements and obstacles. The identified success factors are: having a clear purpose, ownership, and budget, allocating full-time resources, creating a plan for resource use and infrastructure, fostering a positive collaborative environment, involving local authorities in regulatory changes, engaging businesses, ensuring good communication, and involving local users as active participants and testers. These factors are listed in no particular order. (IMPELLO, 2020, p. 12).

Living Labs Theory

Living Labs are environments for involving users in innovation and development (Følstad, 2008).

Hvitsand & Richards (2017) has defined living labs as "*forum for innovation, applied to the*

development of new products, systems, services, and processes in an urban area; employing working methods to integrate people into the entire development process as users and co-creators to explore, examine, experiment, test and evaluate new ideas, scenarios, processes, systems, concepts and creative solutions in complex and everyday contexts." (Hvitsand & Richards, 2017, p. 13).

Living labs can be understood as "experimental environments"; as physical or virtual places where actors collaborate to create, test and experiment with new solutions in a "real life" context (Westerlund & Leminen, 2011). Dutilleul et al., (2010) has identified 4 different perspectives on Living labs.

1. Stakeholders. A living lab can consist of an innovation system consisting of organized and structured multi-disciplinary networks fostering interaction and collaboration. This could be universities, businesses, government, and privet persons.

2. Real-Life Setting. Real-life monitoring of a social setting generally involves experimentation of a technology. What is considered "real life" varies, and previous research has focused on everything from isolated individual areas, at the university, in someone's living room or a neighborhood.

3. Experimenting. An approach for involving users in the product development process. Based on this, living labs can be considered an arena where experimentation occurs within a safe framework. This enables the actors to gradually arrive at new solutions in an incremental and "learning by doing" approach.

4. Network. Organizations facilitating the network, maintaining, and developing its technological infrastructure and offering relevant services.

While Living Labs have been the subject of academic publications and research, there is a need for more quantitative and comparative studies to assess their additional value. Living Labs are a flexible concept that allows for various methodologies and research approaches to be utilized, making it akin to an empty box waiting to be filled. (Hossain et al., 2019).

Benchmark Theory

The benchmark theory is for organizations to evaluate their operations in relation to those perceived to be the best within a certain industry. Benchmarking is comparing products,

working methods, or the like based on criteria or default values, especially to achieve improvements. The word benchmark is 'reference point, the criterion' (Dahl, 2021).

Benchmarking is a tried and tested process that can significantly enable organizational learning and enhance organizational performance (Karlöf, 1995). There are several approaches to benchmarking. Longbottom (2000) has identified four key stages of benchmarking process: planning, analysis, implementation, and review. Karlöf describes a five-stage process for benchmarking, as showed in the figure below:

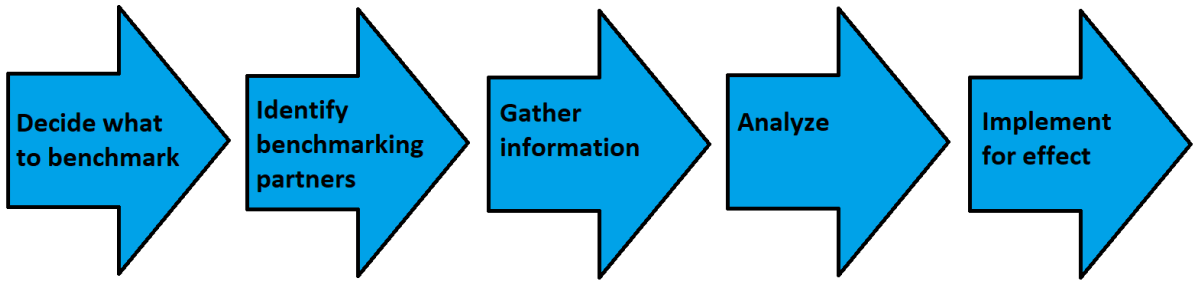

Figure 6. Benchmark process. Made by author (Karlöf, 1995).

Benchmarking is a learning process where companies identify a benchmark to investigate and understand the underlying best practice and implement strategies in their own company to become equally good in that field (Longbottom, 2000). The general perception that benchmarking is to compare key figures is only partially correct. Although most benchmarking exercises involve comparing achievements or achievements in one form or another, this is not the purpose of benchmarking (Karlöf, 1995). For example, knowing that the competitor has a 15% more cost-effective production has little value. Instead, the goal of benchmarking is to understand how the competitor has become more efficient and how their own company can apply the competitor's experiences in its organization.

Karlöf (1995) has described three different types of benchmarking:
Internal benchmarking, comparison within own business.
External benchmarking; comparison with similar external activities.
Functional benchmarking; comparison between functions or processes in different industries.

Motivation

An organization that has a high level of motivation is able to retain competence and utilize this competence. Motivated organizations want to give something extra, utilizing their skills to improve operations and achieve success (Jacobsen & Thorsvik, 2019). Organizations

that are motivated are more likely to achieve operational and financial benefits, leading to a sustainable competitive advantage in the long run (Wright, 2001). To determine the most significant motivation of the testbeds, a list of motivational factors is created. These motivations provide insights into the satisfaction level, strengths, knowledge, and skills of the organization (Hackman & Oldhams, 1974).

To clarify motivation in different categories, three expressions have been selected:
- Objectives: a thing aimed at or sought; a goal (Cambridge Dictionary, n.d.-c).
- Feature: have as a prominent attribute or aspect (Cambridge Dictionary, n.d.-c)
- Agenda: significance in the matters in which they have influence, "Things to be done" (Cambridge Dictionary, n.d.-c).

Lessons learned theory

Lessons learned describe how an organization can use experiences acquired from earlier activities to develop knowledge and understanding for future behaviours and actions and implement a change (Davenport & Prusak, 1998). A lesson is not learned until something changes as a result. Bailey (2005) describes lesson as follow:
"*A lesson is truly learned when we modify our behaviour to reflect what we know*". (Bailey, 2005, p. 1).

It's easy for an organization to learn from experience if the experience is strong enough, especially from negative experiences. An organization can share their obtained experience and learn it from other organizations, just like parents share knowledge and experience with their kids. It's a lot more challenging but a lot more beneficial to learn about the experience of other organizations (Zambruski, 2008). It's important to distinguish from the term's *lessons learned* and *best practice*. Lesson learned is "*an innovative approach or work practice that is captured and shared to promote repeat application. A lesson learned may also be an adverse work practice or experience that is captured or shared to avoid recurrence.*" And best practice is "*a process, technique, or innovative use of resources, technology, or equipment that has a proven record of success in providing significant improvement to an organization.*" (Bailey, 2005, p. 4).

The lessons learned practice can be a powerful tool for organization, but it is important to be aware of the hinders for implementation. The main barriers for this are the lack of follow-through and application, senior management, culture, and time issues (Milton, 2010).

Lessons learned systems are common in a business that manages project management. (Milton, 2010). The lessons learned tool fits projects very well because of the natural nature of a project. Typically, project has a relatively short timeline where the same persons who started the project will finish it (Tidd & Bessant, 2013). They will create a new project shortly after completion, where experience from previous projects has a benefit. During the debriefing of a project or post-project, the lessons learned tool can be a powerful tool to gain new knowledge, avoid future mistakes, and find the contributing factors for success. The project manager can use a template to state what went well for the project, what didn't go well and what needs improvement. During project closure, the entire project team and stakeholders should be included in the debriefing session (Zambruski, 2008). The first step is a process of generalising, analysing, and reviewing in a past project. To identify the lessons, find the roots behind what happened and recall any positive or negative experience. The second step is the assigning action, to follow up a lesson, to document new process or improve existing documents. And the last step, share the new process with the people who needs it (Milton, 2010).

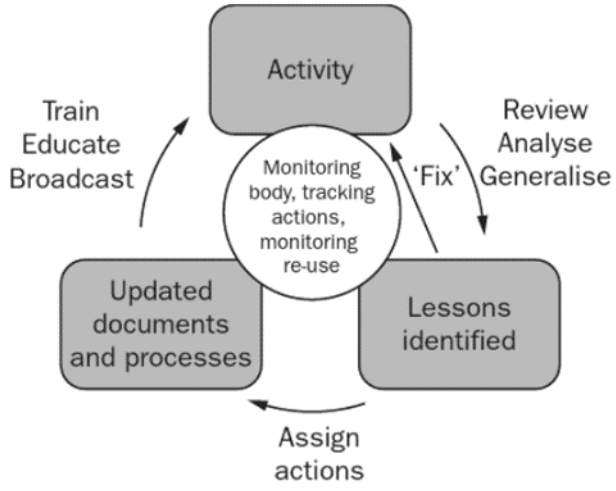

Figure 7: The learning loop. (Milton, 2010, p.16)

Kolb's learning cycle and learning methods

A common definition of learning is "*the acquisition of knowledge or skills through study, experience, or being taught*" (Svartdal, 2022) While Kolb's definition is "*Learning is the process whereby knowledge is created through the transformation of experience."* (Kolb, 2014, p. 38).

Kolb's learning cycle is a tool to experiential learning. It a four-step learning process, in other words, concrete learning reflective observation, abstract conceptualization, and active experimentation. This learning process is presents as a learning cycle. The learning cycle is a continuous process consisting of the four stages (Kolbs, 2014).

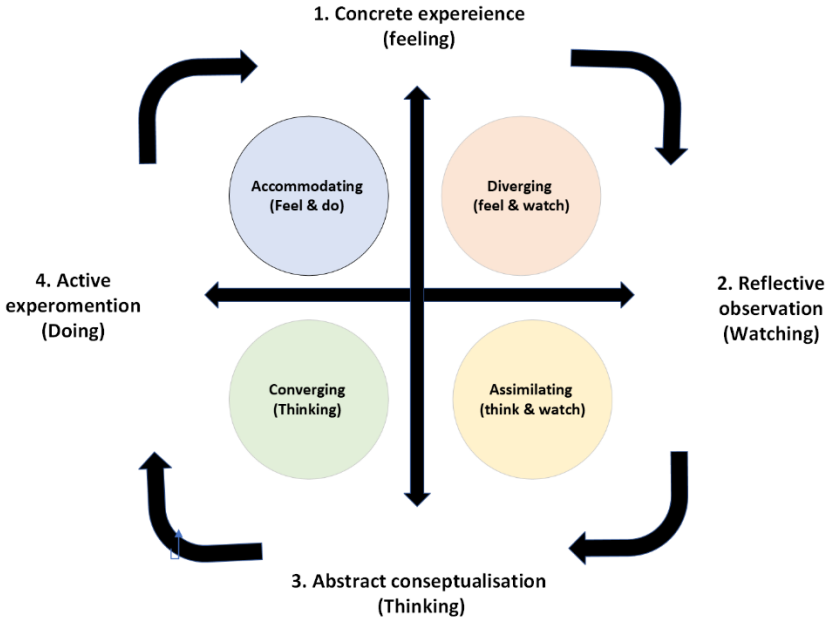

Figure 8. Kolb's learning cycle. Made by author. (Kolb, 2014).

Concreate learning is when any learner is introduced to a new experience or looks at a past experience in a different way. The learner must do it himself for learning to occur. Reflective observation is when the learner is promoted to reflect on the experience from their personal bias. The learner is taking a step back from doing to reflect and review. Abstract conceptualization is when the learner modifies the existing ideas based on their own reflection or forms new ideas. And finally, active experimentation is when the learner applies the ideas formed to their surroundings. It happens when the leaner considers how to put new knowledge into practice (Kolbs, 2014).

To the stages in the learning circle, Kolb links two dialectical dimensions that coincide with the stages in the circle. One is the grasping dimension, and the other is the transformation dimension. The grasping dimension extends vertically from the concrete experience, which gives understanding through experience, to the abstract conceptualization, which provides understanding through perception. It is about understanding through active perception versus understanding through analyzing and generalizing. The transformation dimension extends horizontally from reflective observation, which gives transformation via meaning attribution, to active experimentation, which provides transformation via expansion.

And with the two dimensions, four learning styles is created (Kolb, 2014):

1. Diverging – The learner prefers to watch and learn from other people, like coaching.
2. Assimilating – Prefer clear and concrete information and enjoy ideas but not their practical application.
3. Converging – Enjoys theory and ideas, solving practical problems and experimenting with new ideas.
4. Accommodating – Enjoys learning through doing and use own reflection rather than a detailed analysis. In other words, solve problems spontaneously and excited with new challenges.

Learning communities and **cooperative learning** are two important terms. A learning community is a structure or space for organizations to align around a shared goal (Voosen, 2008), and cooperative learning is a strategy used for a group that aims to enhance their understanding and learning experience of a subject (Johnson, 2002).

In **problem-based learning** (PBL), learners use challenges from the scenario or problem case to define their own learning objectives. Problem-based learning is suitable for group learning, where each learner starts independently and starts with self-directed study before discussing their findings with the group and refining their acquired knowledge. Problem-based learning is not about problem-solving (per se) but uses appropriate problems to increase understanding and knowledge (ZHOU et al., 2021).

Wood (2003) has described the advantages and disadvantages of problem-based learning.

Advantages of problem-based learning: It fosters *active learning* (active learning is defined as activities that participants do to construct knowledge and understanding and require the participants to do higher order thinking (Brame, 2019), improved understanding, and retention and development of lifelong skills. PBL allows the learner to develop generic skills and attitudes desirable in their future practice. PBL facilitates an integrated core curriculum. PBL is motivation for the learner, and the process requires all learners to be engaged in the learning process. PBS fosters deep learning (the learner interacts with learning materials, relates concepts to everyday activities, and improves their understanding), and it is a constructivist approach i.e., the learner activates prior knowledge and builds on existing conceptual knowledge frameworks (Wood, 2003).

Disadvantages of problem-based learning: Require more human resources and staff have to participate in the tutoring process. Large numbers of learners need access to the same 'library' and resources simultaneously. And the learner may have information overload and be unsure how much self-directed study to do and what information is relevant and valuable (Wood, 2003).

With **practice-based learning**, the learner combines theory and work experience with a strategic, reflective process throughout the duration of the learning. The goal is for the learner to become a self-sufficient professional who can develop, measure, redesign and grow their practice over time (Loose, 2020). Practice-based learning has a lot of similarities with problem-based learning. The difference is in problem-based learning, they learn from a problem, while practice-based learning learns from practical experience and knowledge.

Collaboration theory

Working together through collaboration can enhance how organizations solve problems, leading to greater innovation, streamlined processes, increased success, and enhanced communication (Andriessen & Baker, 2020).

According to Richardson et al, collaboration involves fully integrating all participants and working together towards a shared goal. This approach encourages staff to share their expertise beyond their own departments, leading to greater productivity and teamwork (Richardson et al., 2019).

Effective collaboration depends on establishing trust and partnerships, acknowledging interdependence, creating a shared vision, setting common goals, and fostering commitment among all stakeholders involved (Waayers et al., 2012).

Coopetition theory

The testbeds are established in regional clusters (Porter, 1998) in Norway. Where the businesses are connected through various forms of local cooperation, knowledge flow and competition. In addition, actors in the cluster must recognize that they are part of a cluster that results in joint actions to strengthen the cluster. This creates complementarity and knowledge flow in the cluster (Power & Malmberg, 2005). But how much competition there is between the regional clusters in Norway is unknown, but studies of competition between wine clusters in the world, where regional competition between clusters occurs (Hira, 2003). And then it is

almost certain that there is a level of regional competition between the clusters where the testbeds are established. The testbeds are established in clusters, where it is reasonable to think that there is a factor of regional competition. Therefore, coopetition theory is relevant for this thesis.

Coopetition is a combination of cooperation and competition. Sometimes, competing companies benefit from collaborating to increase their capacity to compete in the market. This concept is commonly used in technological fields, where sharing information can enhance products and provide a competitive advantage to all participants (Brandenburger, 2011). Instead of creating winners and losers, the goal is to generate higher profits and lifetime competitors. Therefore, cooperation and competition are considered much more favourable for everyone involved. This concept is sometimes used on a micro-scale in school/university settings, and macro-scale for larger companies (Brandenburger, 2011).

It is important to balance cooperation and competition to have a successful coopetition and to avoid conflicts (Das & Teng, 2000, a). Conflicts often arise when competitors have to work together to solve innovation projects. Previous research has shown that conflicts are due to the inability to balance three sets of tensions (Das and Teng, 2000, b). The first tension is a short-term focus, the actors are no motivated to build a relationship. Second is lack of common goals, and the third is lack of flexibility. (Das and Teng, 2000, b). Nevertheless, some studies indicate that one can achieve cooperation and flexibility even in short-term partnerships (Swärd, 2013).

Collaboration is based on human relationships and contracts are never fully comprehensive. Building trust involves taking the first step and being open to risk-taking. Organizations need to offer something valuable to establish trust and receive something in return. The project's initial phase is pivotal in determining whether the collaboration will be successful or not. Therefore, the behavior exhibited during introduction meetings is critical. (Cygler et al., 2018).

Coopetition is not just about non-competing actors working together; it also involves competitors collaborating to develop new innovations (Brandenburger & Nalebuff, 2011). And with a little socializing on top, it is crucial to have clear guidelines not to cross the line to avoid conflicting with the law (Clarysse et al., 2014). Many established collaborations have connected with experts in the field of competition to guarantee compliance with regulations.

While collaboration may seem attractive, establishing trust in the relationship becomes more challenging when competing. Unlike a merger with a competitor, where competition stops overnight, competitors continue to compete while building enough trust to make collaboration successful. (Das & Teng, 2000, a,) (Clarysse et al., 2014) (Bengtsso et al., 2016). Managing collaborations within an ecosystem can be challenging. Without hierarchical control, other means must be found to ensure resources are delivered to the project. This difficulty increases as the number of parties involved grows. A leadership role can be taken to address this issue, but the amount of authority placed in the leader's hands must be carefully considered. (Clarysse et al. 2014) (Fernandes et al., 2019).

Drivers and barriers theory

The definition of drivers given by Cambridge Dictionary is "*Something that makes other things progress, develop, or grow stronger"* (Cambridge Dictionary, n.d.-c). The term drivers are relevant when it comes to change, processes, and innovation. The drivers are the forces or activities that encourage and support the change. Drivers can further be grouped into internal and external drivers. Internal drivers are supporting factors like support and encouragement that can drive innovation forward, and external factors like financial, regulation and incentives (Walker et al., 2008). Below is a table showing some relevant internal and external drivers.

Internal	**Reference**	**External**	**Reference**
Improve quality	Pil and Rothenberg (2003)	Legislative and regulatory compliance	Hall (2001)
Desire to reduce cost	Carter and Dresner (2001)	Pressure by customers	Hall (2001)
Employee involvement	Hanna et al. (2000)	Customer demand	Carter and Dresner (2001)
Reduce cost	Handfield et al. (1997)	Gaining competitive advantage	Sharma and Vredenburg (1998)
Reduce pressure	Green et al. (1996)	Stakeholders	Sharma and Vredenburg (1998)

Table 1: Internal and external drivers. Made by author. (Walker et al., 2008).

Regarding innovation can drivers be an important source of innovation. The two most dominating drivers for innovation are the need-pull and knowledge-push (Tidd & Bessant, 2013). Need-pull innovation is a drive that comes from a need, while knowledge-push drive means an innovation forming from new knowledge.

Barriers are defined as “Something that prevents something else from happening or makes it more difficult” (Cambridge Dictionary, n.d.-c). In other words, barriers are the forces or activities that prevents a change. Barriers can also be divided in internal and external groups (Walker et al., 2008).

Internal	**Reference**	**External**	**Reference**
Costs	Wycherley (1999)	Regulations	Porter and van de Linde (1995)
Lack of legitimacy	Greer and Bruno (1996)	Industry specific barriers	Zhu and Sarkis (2006)
Lack of commitment	Carter and Dresner (2001)	Poor supplier commitment	Wycherley (1999)

Table 2. Internal and external barriers. Made by Author. (Walker et al., 2008).

Occasionally a force or activity can be considered a driver and a barrier simultaneously. In the past decade, stricter environmental policies and demand increased. New political demands can be viewed as a driver for change. However, it can represent a barrier to change as well. When a new policy demand is in force, it creates a change that needs to be followed. At the same time, this can provide a barrier that can be hard to adjust for specific groups (Blomberg et al., 2017).

Summary and theoretical framework

The literature review provides a detailed explanation of what a testbed is, how it is built, and its important elements and characteristics. All the testbeds used in this assignment meet Vinnova's category level 3 definition and have been approved by authorities as an arena for testing in specific coastal areas where other activities occur. To gain a better understanding of what a testbed is, the living lab theory can be helpful. While some aspects may differ, the key principles of the living lab are relevant to comprehending the testbed concept. A benchmark is a way to learn and improve. By comparing the benchmark of different testbeds, valuable insights can be gained into their effectiveness and whether their methods can be used by others. The motivations behind each testbed can give an idea of their specific areas of interest and status. For instance, one testbed may focus on developing autonomous ships while another may prioritize creating support functions like reference or anti-collision systems. It's essential to learn from lessons learned not only within the current testbed but also for other testbeds. Avoiding mistakes and challenges that others have experienced can be highly advantageous. Additionally, the theory emphasizes the significance

of having a long-term perspective and sharing knowledge. Kolb's learning cycle describes the various ways in which people learn. It outlines the fundamental methods that organizations and individuals use to gain knowledge. The thesis uses terms such as cooperative learning, learning communities, problem-based learning, and practice-based learning, which is also explained in the literature chapter. One crucial aspect to consider is the collaboration and coopetition theory. It's important to examine how different testbeds are collaborating with each other. The key factors to be considered are effective collaboration and coopetition, which will help us to identify the competitive situations between the testbeds. The article discusses the drivers and barriers that impact the current opportunities and challenges faced by testbeds.

Two frameworks, "status" and "experience," have been developed to distinguish between theories. These terms are only used for identification and have no further importance. The status framework provides an overview of current testbeds, while the experience framework focuses on lessons learned, learning, and collaboration to answer research question 1. To answer research question 2, a collection of the drivers and barriers and the literature will address which findings impact further development. And findings from RQ1 and RQ2 will hopefully provide how the learning can be improved between the testbeds.

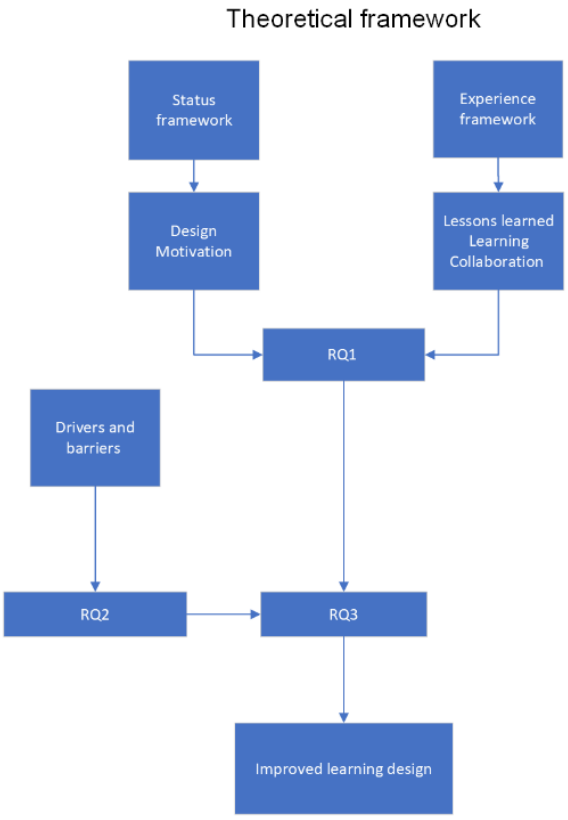

Figure 9: Theoretical framework. Made by author.

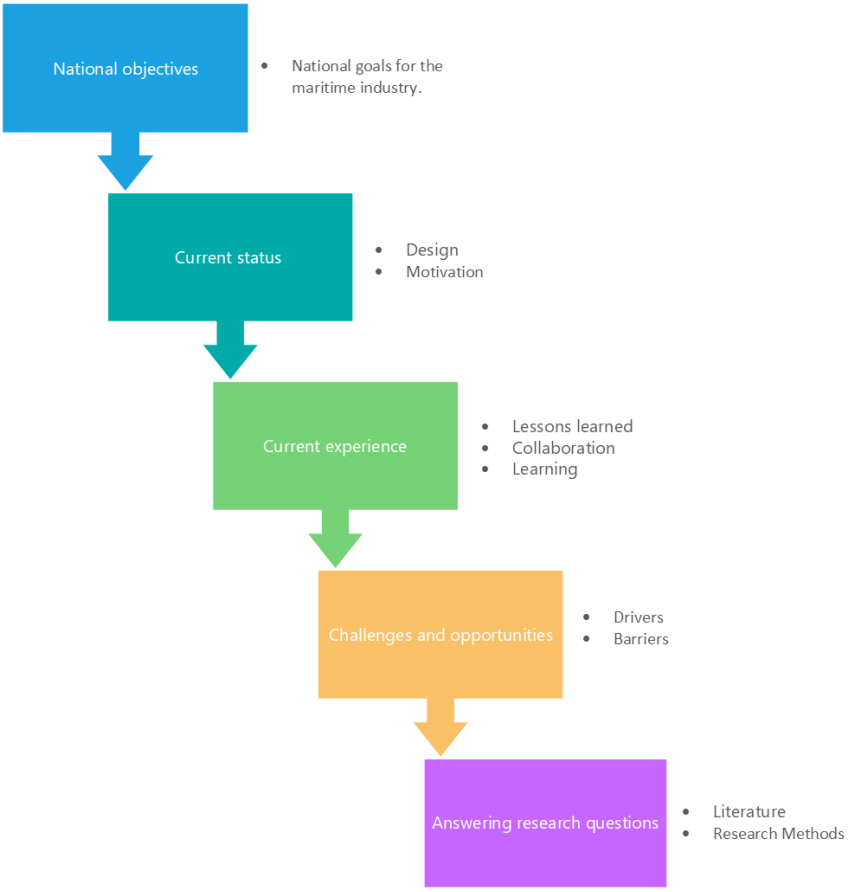

Figure 10: Waterfall presentation of the theoretical framework. Made by author.

Research method

General introduction

Research methodology explains how the study gathers and analyzing data. This chapter will explain the selected methods used in this thesis and how the data is gathered to answer the research questions. For any research and study, it is important to use the appropriate methods to collect relevant data. This chapter will explain how data has been interpreted to avoid ambiguity for future inquiry and be applicable. This ensures an ethical and truthful dissertation.

What is method?

A method is a specific approach used to gather information and ask questions. It bridges the gap between empiric and theories, connecting empirical evidence with reality. In scientific research, a method outlines the requirements for collecting empirical evidence in order to produce reliable and valid knowledge about reality. Strategies are employed to explain the collected data, and the domain of the method lies between empirical evidence and speculations/theories. The approach taken to uncover reality is defined by the method. In practice, this involves a focus on collecting credible empirical evidence about reality in the best way possible, to answer the question at hand. A suitable method is vital for conducting research yielding valuable and valid information (Jacobsen, 2015), (Frankfort-Nachmias et al., 2015).

Why method is important?

To ensure the integrity and credibility of collected empirical evidence, a systematic method is utilized for research. This includes the collection of data, information processing, and presentation. Validity and relevance are essential components of the empirical evidence, meaning that the collected experience must answer the research question accurately. Two types of validity and relevance are employed in the scientific method: internal and external. Internal validity pertains to whether the data covers the conclusions made, while external validity and relevance concern generalization and transferability to other contexts. The method also guides researchers through specific stages during an investigation, ensuring a systematic approach (Jacobsen, 2015), (Frankfort-Nachmias et al., 2015).

How to supply suitable and solid methods for a thesis.

The researcher's perception of reality determines their choice of research method. This includes formulating the research question, which guides the selection of a method. Choices must be made regarding how the thesis will acquire knowledge about reality, such as whether to use an inductive or deductive approach, focus on individualism or holism, distance, or closeness, and collect quantitative or qualitative data. Once these choices are made, it becomes easier to find a suitable and solid method for the thesis (Jacobsen, 2015), (Frankfort-Nachmias et al., 2015).

Research design

Early in the process, a concept map was created to represent the research and available design visually. A concept map can be charts, tables, timelines, or graphic organizers. Concept maps are a powerful investigation strategy as they give researchers a clear overview of the big picture from the beginning (Nist & Holschuh, 2000). Together with the ladder of abstraction method, the initial concepts of literature theory, methods, and research design were collected and organized into a concept map to visually display the findings and make sense of the information by establishing meaningful connections. The methods chosen for a thesis will depend on the thesis investigation (Johannessen et al., 2018).

This thesis follows an inductive approach, which begins with observing empirical data and then develops a theory from it. It is important for the theory to be based on reality, so the researcher must gather data without any preconceived notions. The qualitative approach is used in this thesis, as reality is too complex to be reduced to numbers alone. Instead, information is gathered through descriptive words to capture the subject's nuances. Since the problem at hand is exploratory, a method that produces detailed and nuanced data, is sensitive to unexpected conditions, and is open to contextual factors has been chosen. This approach focuses on a small number of survey units to better understand the subject. (Jacobsen, 2015), (Frankfort-Nachmias et al., 2015), (York, 2023).

To conduct the thesis effectively, *case study* and *open interviews with semi-structed interview guide* were chosen. Case study method is suitable to answer questions like *how*, *what*, and *why* about current events and topical phenomena (Yin, 2014). A case study can be defined as the study of one or more units of analysis, phenomena, or systems, where the purpose is to generate in-depth knowledge about the case and its participants (Tjora, 2018).

Furthermore, Yin (2014) elaborates that in a case study, one examines a phenomenon in its real context. Therefore, what counts as a case can vary depending on what the researcher is exploring to gain knowledge of and can embrace studies of individuals, societies, processes, or events. Therefore, it is essential to define what you want to study (Tjora, 2021). Among different case study methods, the comparative case design was deemed most suitable for addressing the research questions. This approach involves gathering information from multiple, specific situations. Increasing the number of cases enhances the likelihood of extrapolating findings to other situations. By comparing cases, causal relationships and causality can be revealed. (Jacobsen, 2015), (Frankfort-Nachmias et al., 2015), (York, 2023).

In this thesis, the application of lessons learned, collaboration, learning, and design comparison with the different testbeds are chosen to limit the study to the testbed's current position.

In an open individual interview, the respondent is questioned in a conversational manner. Information is gathered through spoken words, sentences, and stories. Typically, these interviews are conducted in person, but for this thesis, it was conducted through Teams. During the interview, the examiner takes notes either by writing or recording audio while discussing various topics with the respondent. There are minimal restrictions on what the respondent can share. The examiner then analyzes the gathered information to produce the conclusion (Jacobsen, 2015), (Frankfort-Nachmias et al., 2015), (York, 2023).

Individual interviews are important for collecting valid data as the design measure personal views on a phenomenon or situation. When it comes to reliability will the researcher presence can create special results, known as the interview effect, and the context in which the interview takes place can also have an impact on the data collected, known as the context effect. Therefore, the connection between the method of individual interviews and reliability is crucial to consider. (Jacobsen, 2015), (Frankfort-Nachmias et al., 2015), (York, 2023).

A brief overview of the research process for this thesis, three problems were identified and formulated. Afterwards, a comparative case design was chosen as the research approach. Next, due to limited information on the testbeds, a qualitative method was deemed suitable, and individual interviews were conducted to gather data. However, there were some limitations in selecting enough responders, since only four testbeds were established, so maritime authorities, nearby clusters around the testbed, and interest organizations were also

interviewed to increase the number of responders. The analysis and interpretation of data are further explained in the data analysis chapter.

Refined research questions

After the first round of investigating empirical sources for testbeds, some temporary research questions were concocted. Then began the process of narrowing down and specifying. The development of a problem is a long-term process, and it can be challenging to know when to stop (Jacobsen, 2015). The quality on the research question is central. If the research questions are inadequate, the research is usually also flawed (Frankfort-Nachmias et al., 2015). A research question should be clear, focused, complex, and arguable (The Writing Center, 2018). After studying the topic, the research questions were narrowed down to researchable topics and is as follows:

RQ1: What is today's situation with the Norwegian testbeds regarding design, motivation, lessons learned, collaboration and learning (between testbeds) expressed in the testbeds today?

RO2: What are the most significant drivers and barriers today for the testbeds and their impact for the further development of the testbeds?

RQ3: How can the learning be improved between the testbeds?

The following research questions contain exploratory questions words, written has a question. Address something that exists with valid data i.e. avoids speculations of the future. Research questions are narrowed down to answered with limited resources and time. And hopefully lead to new valuable knowledge.

Population and sample

The participants were chosen after the strategic selection method (Tjora, 2021). With this method the researcher chose the participants which can explain or provide statement in a reflective way about the topic in questions. When conducting an individual interview, the researcher selects specific individuals based on the information they need to gather (Jacobsen, 2015). The criteria for the participants for the participants was as followed: (1) the person need to be active in the testbed, (2) has a leading role, (3) consist of representatives from different sectors in the testbeds.

Determining the appropriate sample size in qualitative research projects can be achieved through various methods. One commonly mentioned technique in the methodology literature is the saturation approach, where data collection continues until the researcher gathers all necessary information. However, this approach may not be ideal for every qualitative research project (Glaser & Strauss, 1999). The respondents were selected based on their ability to provide useful and relevant information. An email was sent out to each testbed to initiate a conversation with potential respondents. After establishing contact and completing the interview, the respondents were inquired about any information they may have on a potential responder. This approach is known as the *snowball method*. While it can be very effective, it is also quite demanding. Firstly, each interview must be carefully analyzed before proceeding to the next. This process can be time-consuming and resource intensive. Secondly, there is no guarantee of success, as the method can sometimes come to a dead end. In such cases, researchers must regroup and try again (Jacobsen, 2015), (Frankfort-Nachmias et al. 2015).

After 14 interviews, a satisfactory database of information was obtained, and the snowball was starting to move to other types of testbeds, for example, windfarms testing sites, energy, and land-based testbeds. Therefore, it was natural to stop with 14 interviews with good validity. The sample consist of 6 persons from the testbeds. 4 persons in the clusters, 2 persons in the authorities and 2 persons from interested organizations. A total of 15 interviews were completed, but the one interview was not recorded on tape and analyzed. See the 'Conducting the interviews' chapter for more information.

Data collection method

Qualitative interviews were chosen as the data collection method for this thesis. Elements that characterize a qualitative interview are it uses open-ended questions, no rating scale or rubric is needed, responses are non-numerical, small sample size is used, unstructured, semi-structured, informal interviews and focus group discussions (FGD) are used. Questions is structed for the participants to answer on their own. The researcher may ask follow-up questions. Not applicable for blind and uneducated (no read, no write) participants (Jacobsen, 2015), (Frankfort-Nachmias et al. 2015). The question used in this thesis is an open-ended type with a semi-structured interview guide. The participants received the interview guide on email before the interview and had the option to perform an interview where they are prepared before the interview.

Semi-structured interview guide

In advance of the interviews, a semi-structured interview guide was prepared based on the thesis problem and previous research on testbeds and chosen literature. The questions in the interview guide were prepared in advance. Still, the order of these varied according to what was natural in the interview situation (Thagaard, 2013). A semi-structured interview guide gives the researcher flexibility in the interview situation (Tjora, 2021). In the interview, it was positive for the researcher to move freely between the questions. A semi-structured interview guide provided a better conversation flow and the opportunity to change course when the interviewee touched on a topic outside the interview guide. While the interview guide contained questions that ensured that the research questions were answered, there was still freedom in that the interview could take a different direction than first thought. This shows how an interview situation will be characterized not only by systematicity and order but also by improvisation and new directions during the interview situation (Tjora, 2021).

One interview guide was drawn up as a starting point, adapted to the participant's role. This was done so that the questions would be experienced as relevant for the interviewee and so that the person could answer the questions that were asked (Thagaard, 2013). Since the selection consisted of key people and authority employees, some questions had to be adapted to each individual. Such a method becomes more demanding to code and compare the interviewees' answers in the analysis (Thagaard, 2013). At the same time, the purpose of the thesis was not to carry out a comparative analysis but rather to gather the experiences of several people. Based on this, it was estimated that it was more important to adapt the interview guide rather than having a fixed structure. A semi-structured interview will look more like a conversation than an interview, making it natural that the interview takes a different form from time to time. This is also the strength of the in-depth qualitative interview; they can be adapted to each interviewee's unique experience, information, and interpretation (Kvale & Brinkmann, 2015).

The interview guide was structured according to the introduction, reflection, and closing questions. The introduction questions involved questions about the person's profession and position. Such questions at the beginning of interviews are important for establishing good contact between the researcher and the interviewee (Kvale & Brinkmann, 2015). When trust had been built up, the researcher moved on to asking questions requiring the person to reflect on their own experiences. Finally, more open questions were asked to round off the

interview in a good way (Thagaard, 2013). At the end of the interview, the participants were given the opportunity to share additional thoughts and information related to the topics discussed. The same interview guide was used for participants in the interest organizations, the clusters, and the authorities, but design questions were excluded.

Conducting the interviews

The interviews took place from August 2022 to April 2023, and lasted between 30-50 minutes. Before the interview, the participants were sent an email with an information letter about the thesis, a consent form for data storage (Appendix 2) and the opportunity to ask questions about the research and interview. The interviews began with a summary of the consent form's most important points and some personal information about the researcher and the thesis research topic to make the interview situation more personal and friendly (Kvale & Brinkmann, 2015).

Due to the large distance between the different testbeds and time saving, the interviews were conducted digitally via Teams and sound was recorded. A conscious choice was made not to record the interviews with video because this could make the participants uncomfortable, and easier to analyze an audio file in the analysis instead of a video file. In addition, this made the interview feel less formal, as the audio recorder was not visible on the screen. The participants were therefore reminded that the conversation would be recorded, in addition to repeating that quotes and statements are anonymized in the assignment. The participants were also given the opportunity to withdraw from the interview or remove the data from the thesis if they wanted.

Before one interview, the participant responded by mail; as of today, answering the questions in detail as they were formulated was not possible for the participant. But the participant was positive to have a conversation to provide helpful information on a more general level. Therefore, the conversation was not recorded and not used in this thesis, but the information increased the researcher's knowledge.

The interviews were primarily held in Norwegian. This was decided since all those involved in the thesis were Norwegian, and interview guide was also written in Norwegian. It was considered to conduct the interviews in English, but the participants should be as comfortable as possible during the interview in their native languages. The transcription and

analysis were also done in Norwegian. It made it easier for the researcher to be able to categorize and understand the meaning of the answers given.

After the first interview, it was realized that not enough time was spent on the warm-up questions. This was observed by the fact that the participants answered briefly and concisely and needed several follow-up questions at the start, before the person further in the interview became more self-driven in their reflections. Warm-up questions are intended to build a relationship between the participants and researcher, but they are also intended to 'warm up' the participants for the reflection questions later in the interview (Kvale & Brinkmann, 2015). In the later interviews, slightly longer time was spent in the beginning and more warm-up questions were added to create a safe and comfortable interview atmosphere.

Follow up email

To present the collected data, a table was created to categorize the testbeds. During the development of the table, some new questions were added to further categorize the testbeds. Therefore, the participants were contacted again by mail and asked to provide information to the table either by a short interview or answering the mail. Unfortunately, the response was inadequate. One responder claimed not having the necessary information, while others stated that they had already given all relevant information during the initial interview. Additionally, some participants did not respond at all, which could be due to disinterest, being busy, or having a backlog of emails (Dillman et al., 2014). Thus, a decision was made to form a table using the accessible data.

Data analysis method

Qualitative analysis involves reducing the text to smaller components (words, sentences, paragraphs), then tying these elements together, and then trying to understand the parts considering the whole that is formed. This will usually lead to seeing the parts in a new light, so that the analysis is extended to a careful review of the individual parts (Jacobsen, 2015). The analysis aims to organize and make sense of the information gathered from interviews. However, qualitative researchers often face challenges during the analysis stage, which can lead to difficulties later in the research process (Krumsvik, 2014). This thesis builds on the following data analysis methods with an interpretation-based approach. Content analysis (Krippendorff, 2019), parts of Kvales 5 form of analysis (Kvale & Brinkman, 2015), recontextualization (Linell, 1998) and Social Network Analysis (Bodin et al., 2020).

Interpretation-based approach

The data analysis is based on an interpretation-based approach. This approach suggests that discussing an objective reality in social research may not be suitable. The reason for this is that the subjects of study in social sciences, such as families, societies, and organizations, are not physical entities, but rather socially constructed phenomena. An organization naturally consists of several physical things such as people, machines, and buildings. However, an organization is more than just a group of people. It assumes that everyone is working towards the same goal. Whether people work towards the same goal is a highly abstract phenomenon and will thus be difficult to define as something purely objective. The researcher's perception of reality in their findings will vary depending on the source of information, which is the research object (Jacobsen, 2015).

Content analysis

Content analysis involves reducing what is said in an interview or observed in people's behavior to a smaller set of more meaningful categories. The goal is to identify the relevant categories and give them meaning. After categorizing the interview or observation, the next step is to assign units to each category and compare similarities and differences between units linked to the defined categories (Krippendorf, 2019).

Kvales 5 forms of analysis

This thesis has used part of Kvales 5 forms of analysis to create a recontextualization process. The 5 forms of analysis used in research interviews are meaning condensation/coding, meaning categorization, narrative structuring, meaning interpretation, ad hoc methods (Kvale & Brinkmann, 2015). Given the available time and resources, the meaning condensation and meaning categorization is used in this thesis.

Meaning condensation/coding means the researcher shortens the participants' statements to short, precise formulations (Kvale & Brinkmann, 2015). This means that the researcher must be as objective as possible and that one is able to shorten the content so that one is faithful to the participant's statements. There could be some long answers where the participant spoke freely about a topic. A lot of interesting information was given, so the challenge was to condense the answer into short and concise answers that were true to the participant's statements. The interview transcription was read through several times, and

possible digressions that were not within the scope of the interview guide were removed. An important factor was to analyze the statements as open-mindedly as possible and to thematize the statements from the participant's point of view (Kvale & Brinkmann, 2015). Finally, the unity of opinion was examined in light of the thesis's purpose.

Categorization is a way of structuring the interview material, where the meaning of long interview statements is reduced to a few simple categories (Kvale & Brinkmann, 2015). They were then categorized based on the condensation of opinions. Some categories were prepared in advance at a theoretical level (*concept-driven*), while others were developed directly from the interview material (*data-driven*).

Kvale and Brinkmann (2009) mention three different interpretation contexts and validation communities. *Self-understanding:* here, the researcher rewrites the participants views in a condensed form, starting from his own self-understanding. *Critical understanding is based on common sense*: here, the researcher goes beyond reformulating the participants self-understanding and includes a critical reading based on common sense. *Theoretical understanding*: here, a theoretical framework is used for the interpretation.

Recontextualization

Recontextualization is a dynamic process where something transfers from one context to another and thus undergoes a transformation. Recontextualization has a prerequisite for new forms of knowledge to have a formative potential for an established practice (Linell, 1998). When recontextualizing, the statements from the participant are put into a new context, but at the same time remain true to the context in which the statement was extracted from the data material. It is in this process that new knowledge is created (Kvale & Brinkmann, 2015).

Social Network Analysis

Social network theory enables us to comprehend the structure of different social networks, how they evolve, how communication in social networks occurs, and how networks form the foundation for interaction. Network coverage is central to many subjects, including sociology, information science, economics, mathematics, and computer science. Social network theory does not focus on the individual actors' characteristics but instead on relationships between the actors. The overall network these relationships constitute is central to understanding the individual actors and relationships (Carrington & Scott, 2011).

A social network consists of two types of entities, nodes, and ties. A node in a social network analysis could present various actors, such as resources, government agencies or social entities. Ties represent the different types of relationships among these nodes, such as exchanging information, trading, or joint participation in a venue. Usually, one type of relationship is in focus during the analysis (Bodin et al., 2020).

Bodin et al. (2020) developed structural characteristics for social network analysis. First is the macro-level characteristics which refer to the whole network. Centralization, density, or fragmentations is the main characteristics. The other is the micro-level characteristics. This type involves a few nodes that can be thought of as building blocks or patterns that might be prevalent in the network or even missing completely.

With the social network method, one could look at the system-wide factors, e.g., cultural norms or geography, but a centralized network would consist of many building blocks in the wide system. Two nodes connecting to a joint third, but not to each other. The macrostructure is normally used to present cooperative or conflictual relationships. This paper will focus on the macrostructure since microstructure indicates social processes that can reveal actors' intentions, constrained by rules and norms of social behavior, which has not been the focus area in this thesis. But it is important to be aware that the characteristics at the macro-level can also be seen as the social infrastructure that limits and enables individual behavior, so there is an interaction between the macro and micro processes embodied in the network structure (Bodin et al., 2020).

There has been selected seven nodes for this analysis. See table below for details.

Nodes	Definition
Testbed	The defined area for testing autonomous ships.
Other testbed	A testbed can be in collaboration with another testbed. This node is to highlight this connection.
Industry	Refers to projects where big industry actor is involved and has the ownership of the development.
Project	Refers to smaller projects where the academia or start up organizations is the owner or organizer.
Authorities	The Coastal Administration and the Norwegian Maritime Authority.
Interest organizations	Its Norway, NFAS (Norsk Forum for Autonome Skip), Ocean Autonomy and other national platforms that has an interest in the testbed.

Clusters	Local area around the testbed. Local government, stakeholder, academia, and actors.

Table 3: SNA Nods. Made by author.

The analyzing part has used components from the methods mentioned above to reveal new knowledge that can be usable for the interested parties.

Ethical considerations

In this sub-chapter, the ethical considerations that have been taken during the research process are explained. Since the task dealt with personal data, the project was submitted to the Norwegian Center for Research Data (NSD) in January 2023 (Appendix 3). The interview process started in August 2022, but the application was not approved until January. No changes were made to the layout in that interim period.

All interview participants were sent a consent form by email before the interview (Appendix 1), where they were informed about the purpose of the task and what it would entail for them to participate. Information was also given here about the participants right to withdraw from the study, and other rights in connection with the study. Before the interview started with the audio recording, information was given again about the task's purpose and definition. All the participants signed verbally except for one. See the 'Conducting the interviews' sub-chapter for more details.

Ensuring the anonymity of participants is crucial for the thesis. However, the person's connection to the testbeds, clusters, or interest organizations is included to ensure the most accurate and valid results.

Findings

The purpose of this thesis is to focus the attention on the testbeds in the Norwegian sector by investigating their current status, what kind of opportunities and challenges they experience with the concept and how they collaborate and share learning with other testbeds. In this part of the thesis, collected empirical findings are presented, which have been analyzed and discussed in light of the thesis' theoretical framework and methods. The findings are presented in relation to the research questions and follow numerologically.

Research question 1:

What is today's situation with the Norwegian testbeds regarding design, motivation, lessons learned, collaboration and learning (between testbeds) expressed in the testbeds today?

Design

The reason for mapping the design trend is to gather information about the testbeds' business models and levels. This includes identifying their goals and outlining the specific activities they are involved in. Many of the testbeds have been in operation for a number of years, with the oldest one having been active for 6 years at the time of data collection.

During the interview process, it became evident that the testbeds were not designed according to the specific requirements requested. This could be attributed to inadequate planning on the researcher's part. Prior to the interviews, it was assumed that the testbeds were well-established organizations with a defined structure and one or more individuals responsible for coordinating the testbed. However, this assumption proved to be inaccurate. Nowadays, testbeds are considered more of a tool without an organizational background. And little business planning was done prior the opening of the testbed. A quote from a participant when establishing the testbed: "*No business plan or strategy was created; it was just to establish and make available an area that was approved for testing*".

The testbed in Trondheim and Horten is a feature utilized for a research project, while Storfjorden and Haugalandet were established as testbeds for local actors to test autonomous ships.

The Trondheim testbed was created as a living lab concept for local actors in and around Trondheimsfjorden. This area has a history of testing and verifying new technologies and scaling up solutions, and the living lab was established to improve open innovation in the region. The initiators developed a method and procedure for creating a testbed in Norway, and soon after, two other testbeds were opened. Although there was initially great enthusiasm for the new testbeds, it became more of a gimmick to attract attention and lacked any real benefits. The activity level was lower than expected, and it was uncertain how useful the testbeds actually were. It may be more practical to apply for a dispensation for a specific area from project to project, rather than having a testbed. Currently, all testbeds are poorly organized, with difuse structure. Difficult to find the responsibility persons for an external company.

Some important factors in why it has become like this were poor business planning. First, it turned out that there were few relevant actors for testing, and the relevant actors had been testing long before the testbeds were established and continued their everyday operations. Much of the technology used for autonomous testing has low TRL. The TRL (Technology Readiness levels) is a scale that says something about how far you have come in the development process, what documentation exists for the technology's performance, and on what scale (Innovasjon Norge, 2021). The last important factor has been funding. Testbeds receive funding from the state, which has a long process of handling applications and funding. These are the most important factors found in the data collection for why there has been a lack of design and organizational structure for the testbeds.

The testbeds in Trondheim, Storfjorden and Haugalandet are now in the development process to establish a business model. In Trondheim and Storfjorden will work under the same project Fjordlab in the future. In Haugalandet, things are done somewhat differently. They are currently working on establishing the testbed as an independent limited company, separate from any specific project or research center. Horten wants to continue with the current operation with a low organization structure in order to keep costs and complexity low. But an attempt was made in Horten to have a business model prepared for the opening. Various actors around Horten conducted testing prior to the establishment of the testbed. Therefore, Horten employed a person full-time to coordinate the testbed. However, due to the corona pandemic, few new users and the active users continued without involving the coordinator. This led to the employee being reassigned due to low activity, resulting in a

minimal business plan for Horten testbed. Therefore, it is difficult to concretely describe the business model in the various testbeds because the plans can quickly change in such a phase. However, below is an informal table that describes the current situation.

Testbeds	Status	Business model
Trondheim	Planning stage	Be a part of a knowledge centre Fjordlab. Establish an infrastructure where customers can use the equipment for a fee. Provide support with a technician specialised in the infrastructure and research support for data treatment and project management. Collaborate with local expertise, NTNU and SINTEF.
Storfjorden	Planning stage	Be a part of the knowledge centre Fjordlab. Build an infrastructure of sensors and provide free data to all customers and interested parties, to get as much activity in the testbed. Provide support and test equipment.
Horten	Operational	Continue to be a part of the Autostrip project. Keep small organization and provide manager assistants to projects. And focus on the development of a control centre and conducting certification courses.
Haugalandet	Planning stage	Create a corporation with 1-2 employees to be a coordinator in the testbed. Marketing and facilitating test operations.

Table 4: Business models. Made by author.

Motivation

Motivation is an important factor in understanding what the testbeds want to achieve and what is the driving force. The participants were asked openly what they considered was the motivation for the testbeds. A common similarity between all testbeds is being a testbed for all interested actors who want to test and advance in technology, research, and development, pushing the progression forward. Establishing a robust industrial sector is crucial for achieving a competitive edge in the global arena.

The main objectives for **Trondheimfjorden** are to create a living lab for testing autonomous technologies at sea, which will boost research and development in the industry. The testbed will provide a centralized location for researchers to conduct experiments and share infrastructure, rather than having multiple smaller test areas. Additionally, the lab aims to promote collaboration and accessibility for the industry and others, with a national focus on improving the Norwegian industry and global competitiveness. The important features for Trondheimsfjorden are the eco-system with strong actors. NTNU, SINTEF and a great

research system with international recognition, provides a benefit for the testbed to attract customers and new actors to the testbed. And is currently develop a infrastructure of sensors and equipment actors can utilize. Their formal agenda to base on the research and verification of technology and scalp-up innovation. The environment around the fjord is highly focused on research.

The purpose of **Storfjorden** is to create a testbed for ships and innovative green technologies. The goal is to enhance efficiency, minimize noise pollution, and optimize ships for waves, currents, and wind. The testbed will also feature automatic docking and port operations. Additionally, the aim is to make the testbed accessible to everyone so that it can serve as a dynamic laboratory. The special feature with Storfjorden the investment in sensors and how they want to use this data. Instead of having a fee or are a paywall to access the data, they will public all the data for free, without a fee or any commitments. The main agenda is to be a testbed for the local's actors but also invest in the sensor's technology. In other words, the actors will test their innovations, simultaneous will the testbed develop the sensors to get better data and accuracy.

Horten objectives is to stimulate growth for local businesses and industries and attract new companies to the area. This includes improving *control center* and creating a hub for students (Autodrome). The control center for autonomous ships enables one operator to monitor multiple ships. A team of operators will oversee security from a land-based control center, with each operator responsible for several ships. While they cannot remotely control the vessels, they are able to take control if needed (Fenstad, 2021). The control center and simulator they are investing in will be an important feature for the testbed. Not only to create income, but also to be a competitive advantage in that development. Their agenda will be testing of full-scale ships, with a focus on the value chain. That the entire supply chain becomes autonomous, not just parts of it.

Haugalandet's main objectives is to create real and exciting cases, opportunities, and industries. The Norwegian model promotes cooperation and openness in Norway. Bring new technology partners and initiatives to Haugalandet. The feature testbed have is the geography, with busy traffic areas, calm water and high seas, and shipping areas 1-5 in the testbed area. The agenda at this stage is to be a coordinator for testing and marketing.

T**he authorities** (Norwegian Maritime Authority and Norwegian Coastal Administration) are responsible for what is on the sea and what takes place on the sea. In other words, the infrastructure and safety, and have therefore some motivation for the testbeds. They will be involved in development to facilitate testing, support the industry, contribute to technological development, and help the Norwegian industry and maritime actors. And the last motivation is to ensure that the testing occurs safely and appropriately. The testing is harmless to both the environment and any third parties involved.

Lessons learned

The testbeds had limited lessons learned experience during the data collection. As a result, few concrete experiences or innovative approaches/work practices have been captured and shared to avoid recurrence. The interest organizations involved were asked if they had any lessons learned observations for the testbeds or if they had any lessons learned themselves after the testbeds were established. They shared comments that they deemed crucial and relevant for the testbeds but did have any concrete lessons learned. However, the Norwegian Coastal Administration and the Norwegian Maritime Authority had some very interesting lessons learned.

Lessons Learned - Testbeds

	A lesson learned was actually establishing the testbed itself. Because testing has been going on for a long time in the area. To make it more structured and simpler, the testbed was established.
Trondheimsfjorden	More focus on communication, both internally in Norway, but also globally. This avoids misunderstandings and misconceptions. Have an openness, don't mystify what the testbed does, communicate what the goal and visions are. Important to focus on it. And it is important to be clear to whom to communicate.
Storfjorden	Things take a long time in the startup phase. The experience of the time aspect is something they have implemented.

Horten	A lesson learned was to invest in a simulator control center developed by Kongsberg to showcase the potential of the control center. Testbed users can develop technology, improve the operator role, and develop the course framework with this tool. It's a valuable lesson learned. Also, increase the usage of Horten VTS in the testbed.
Haugalandet	No lessons learned from the testbed as it is not yet in official operation.

Lesson learned - Authorities

Norwegian Coastal Administration	They want to change the regulation length of the vessels that require a pilot from 70 meters to 24 meters of conventional vessels. The Yara Birkeland project is the only vessel above 70 meters. And by reducing the length, the Coastal Administration wants to become more active in developing autonomous ships. More actors must follow this guideline and fulfil the requirements to apply for approval to use the waterways. Testing autonomous ships led by academics and scale-up is taking longer than expected. This is because they have less financial flexibility, so the time required for testing has been adjusted. In comparison, the industry with more resources can move faster.
The Norwegian Coastal Administration	Has changed their focus on approving testing and conditions. Instead of going directly into regulations and seeing whether this applies to autonomy, they focus on replacing the person aspect. What are the person's functions and work tasks, how should this be replaced, how do the actors intend to solve this, and how to ensure reasonable safety. Gained more significant learning benefits from larger projects, such as Yara Birkeland, so they are interested in pursuing them.

Lessons learned - interest organizations.

The interest organizations had observations which fell outside the lesson learned definition. But they are included to provide valuable observations, which the interest organizations see as important lessons for improving work practices for the testbeds.

- Have joint and harmonious objectives for the testbeds.
- Find an actor with overall responsibility who is interested in seeing the whole.
- Create synergy effects.
- It's important to have good control over TRL.
- All projects end at one point, and then the actors need to have a place where the data is taken care of, and its integrity is maintained.

Learning and collaboration

To understand the current situation, learning and collaboration are central concepts that have been focused on. One of the basic ideas of testbeds is to create collaboration and improve the exchange of knowledge (NESTA, 2019).

Trondheimsfjorden

Great focus on collaboration and learning in the testbed between the various actors. They have an advisory group with people from industry, academia, and authorities. They keep each other updated on what is happening in the testbed. The advisory group looks at how the industry uses different types of infrastructure and makes recommendations on which projects should be focused on in the testbed and how the testbed should develop further. The testbed has an active website where knowledge is shared. In addition, they are active participants in NFAS and INAS (International Network for Autonomous Ships). However, there has been little collaboration and learning with Storfjorden, but no other testbeds. But Trondheimsfjorden is very positive about closer learning outcomes and knowledge sharing with the other testbeds.

Storfjorden

There has generally been little focus on learning right now. There has been some learning with Trondheim, via the Ocean Space Centre. This will be better when the testbed comes into operation. When it was decided that all raw data produced by the testbed would be available for free and open to everyone, they were confident that knowledge sharing and learning would not be hindered. With the free sensors data, they hope that learning and collaboration will increase between the testbeds and across companies and industries.

Horten

There is little or no knowledge sharing with other testbeds except assemblies and seminars. They publish articles about research findings but acknowledge that there is little knowledge sharing about experiences of how the research was done. Collaboration with other testbeds has been attempted, but it was challenging. Horten is also involved in NFAS. Horten testbeds says they are missing a link between all the testbeds. The link could be a web portal for all the testbeds, where information, lessons learned, standards, and guidelines are available. A web portal could improve both collaboration and learning.

Haugalandet

In Haugalandet, learning and collaboration have yet to be fully in focus. Under the development of the business plan, they have not contacted other testbeds for any advice for designing the testbed. They believe they have enough capability, knowledge, and local experience in Haugesund to establish the testbed. So far, they have been in contact with the catapult centre in Ålesund.

An interesting statement was that Rogaland County Municipality tried to improve learning and collaborated in building a digital platform for test centres in Rogaland. Where the test centres could share information and experience, it was never quite finished because it became too complex.

Authorities

The authorities are a facilitator in all the testbeds and important cooperation partners for the testbeds. The Norwegian Maritime Authority is active in many projects and has an important role in sharing knowledge and experience. But this is aimed at projects. The Norwegian Coastal Administration describes itself as an active and passive actor when it comes to learning. An active actor if the research interests the Norwegian Coastal Administration. Harvests knowledge and develops regulations in line with the industry's research and findings. They notice that it is the industry that delivers results. They know little about what is going on in Trondheim and Storfjorden.

Both departments are positive about a common platform for sharing learning and acknowledge that the transfer of information needs to be improved.

The interest organizations

There is little learning exchange and collaboration currently between the testbeds. There needs to be a link and an actor who can be a driving force and can increase the importance of sharing learning and experiences and establishing collaboration.
They all pointed out that there needs to be a common platform where data is collected digitally, sharing of data, exchange of experience and learning can occur. They find that the testbeds are very positive about sharing learning outcomes, but this has been done to a small extent until now. There are generally few national strategies and national standards for learning. A suggestion is to develop strategy for creating a digital platform for the testbeds. Where testbeds are presented, what they test and contact details. The testbeds need to be an active part in the digital platform. They must be interested in submitting information where they can show examples and historical data because there are many similar projects, such as water bus projects. The learning that takes place in each project stops between the different testbeds. Such a platform can be a link between the testbeds. Some actors have initiated their own actions for a web platform. For example, ITS Norway is currently creating a map where all the testbeds are presented with contact information. The Ocean Autonomy Cluster has developed the website Testination. Where customers can find different locations, get equipment or assistants to complete a test. This is still under development and applies to the Trondheim area. However, they are positive that all the testbeds can actively use Testination. A web portal is profitable for everyone. It provides an overview of what works and what doesn't work. Avoid the same mistakes. The link must take care of each individual's integrity concerning IPR. Able to exchange learning and information at the business level. The link, or the actor with this responsibility, must have continuity and a long-term perspective. The industry must retain its competitive advantage while the public gets enough information to adjust the next level of testing. For now, conferences and seminars are used to present findings.

A web platform that focuses on learning exchange within standardisation, technology development and the order in which things are done, it not only interesting for the testbeds and project managers, but also for land-based and air-based testbeds. Otherwise, there is little

experience of collaboration or competition between the testbeds, but regional competition between the clusters has been observed.

Social Network Analysis

To get a better overview a *Social Network Analysis* was completed to highlight the findings.

Collaboration Macro

The questions in the interview guide were designed from the testbed's perspective to present the current collaboration status for the testbeds. The dashed ties show collaboration between the nodes. From the collected data, collaboration takes place between the various nodes. But there needs to be more data to confirm how strong this collaboration is. The dashed ties have therefore been used to indicate that collaboration is taking place, but it is unknown to what extent.

Solid ties confirm collaboration between the nodes. The greater the tie, the more often term 'collaboration' has been mentioned during the interviews with the relevant node. The most vital collaboration is with the local clusters where the testbed is located. This collaboration does not come as a big surprise since the testbeds are an integrated part coordinated by actors in the cluster. The interest organization is an important factor in promoting collaboration. It is a natural meeting area for different actors to create a national and international forum and an arena for making a collaboration culture. The interest organization also collaborated with all the other nodes and became a tool for establishing communication.

Also, the authorities are important actors when it comes to collaboration. They are responsible for safety on board the test project and infrastructure in the testbed. They are a passive but open role when it comes to collaboration. They are not initiators for innovation and testing in the testbeds but are always assisted when the project owners ask for assistance.

An interesting finding is the collaboration between the testbed and other testbeds. For example, between Trondheimsfjorden and Storfjorden is the process of developing collaboration and cooperation within the Fjordlab project. Other cases of collaboration between the testbeds are project-based, where two testbeds are partners in a project. Despite direct collaboration between the testbeds has not been confirmed from the interviews.

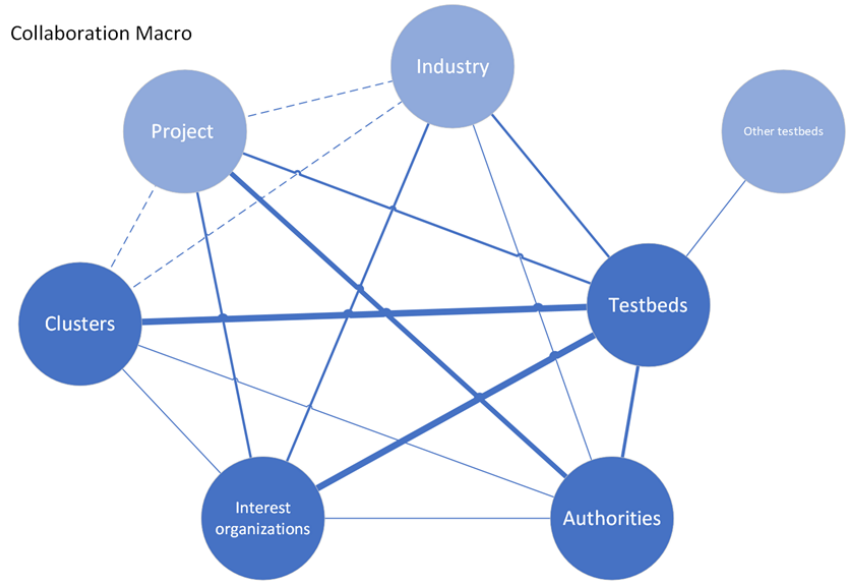

Figure 11: Collaboration Macro. Made by author.

Learning Macro

This analysis is focused on the testbed's experiences when it comes to learning and knowledge sharing. The solid ties are confirmed observations from the data. Most learning is via the interest organizations and local clusters. And a small extent with the project, industry, and authorities. But direct knowledge exchange is primarily with clusters and interest organizations. The dashed ties are confirming that there is a learning outcome with the different nodes, but to what extent is not documented adequately from the interviews.

Learning between the testbeds is at this time not existing. One participant said that it has been tried to establish a forum or platform for the testbeds to share learning and knowledge, but due to unclear structure and ownership, this has proven to be very difficult when it was attempted a few years ago. Storfjorden and Trondheim has start to cooperate under the Fjordlab project. The red line indicates that there is something starting to happen. Currently, there is little focus on learning and sharing between the testbeds, as the testbeds have not properly started the operation.

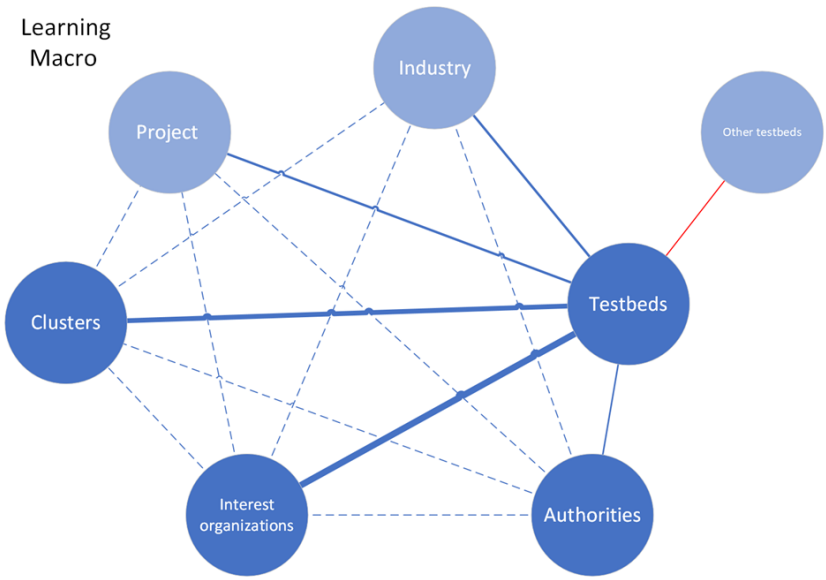

Figure 12: Learning Macro. Made by author.

Table of data

Next page is a table of data to further categories the testbeds and collected data. All information is gathered from the interviews. Keywords marked with* is the researcher perception, interpretation with the meaning coding method.

	Trondheimsfjorden	Storfjorden	Horten	Haugalandet
Established year	2016	2017	2017	2021
Current Operator	SINTEF Ocean	NTNU Ålesund	USN Vestfold	Haugesund municipality (Will be own corporation)
From of organization	Part of Ocean Space Center Trondheim	Part of Møre Ocean Lab	Part of Autostrip project	Under development
Business model	Forming	Forming	Simple structure	Forming
Time scope	No time limit	No time limit	No time Limit	No time limit
Operation status	Partially	Partially	Operative	Partially
Own infrastructure	Yes	Yes	No	No
Investment	90 mill Nok. (Government)	90-100 mill Nok (Government)	No data	3-5 mill Nok (Government)
In vicinity of VTS Area	No	No	Yes	Yes
In vicinity of catapult center	No	Yes	Yes	Yes
Main objectives*	Establish a living lab to boost the research and development for autonomous ships.	Have a maritime testbed to improve the ships abilities in waves, sea current, wind, and reduction in consumption and noise.	Be a testbed for autonomous ships for the Oslofjord area and the south coast.	Develop a local testbed to test new technology and autonomous ships for innovative concepts and solutions.
Feature*	Strong local expertise. Extensive infrastructure	Free data	Control center	Shipping areas 1-5
Formal Agenda*	Research and verification of technology.	Full-scale testing. Develop sensors technology.	Full-scale testing, and value chain development.	Coordinator for testing.

Table 5: Data Categorization table. Made by author.

Summary research question 1

It is absent with the business model right now. In a few years this will be changed. The motivation is high where capital is invested, and in all the testbeds there is motivation to reach the national objectives by developing new technology. There has been little statistics in each testbed about topic asked during the interview, but below some central findings:

Design & motivation – There was little focus on the business plan and business model of the various testbeds when they were established. One attempt in Horten was tried, but it failed due to low activity. As a result, the business model is minimal. This is to keep costs and complexity low. The other testbeds are now in the process of developing a business model and plan for their respective area.

Lessons learned – The lesson learned that was described frequently was the extending of the time period. Many actors were too time-optimistic initially, things took much longer than first thought. This experience has changed how the actors relate to the testbed schedule. Other lessons learned in testbeds was communication with other actors needs to be highly prioritized and focus on land-based solutions for autonomous ship operation. Additionally, VTS areas should be utilized more actively. The authorities have some lessons learned when it comes to the regulations. First, the Norwegian Coastal Administration will make vessels from 24 meters and above compulsory to pilot. This is to become more proactive, and more actors need the approval to use the sea areas. The Norwegian Maritime Directorate has changed the focus for approval of tests.

Learning – Currently, there is insufficient evidence to confirm that learning has taken place between the different testbeds. This finding is significant because it highlights an area for potential improvement. The main reason for this lack of learning is due to the absence of a structured business plan for the testbeds. At present, the focus is on establishing a viable business plan instead of prioritizing learning. The little learning that has occurred has mainly taken place within local clusters such as project-based or industry-based groups, as well as at seminars or assemblies where testbed organizers convene.

Collaboration – Low collaboration level between the testbeds today. A project was undertaken to facilitate collaboration between two testbeds, but unfortunately it was not successful due to various reasons, including an uneven distribution of responsibilities. Since then, there have been no noteworthy collaborations. However, a new collaborative project

called Fjordlab is currently being developed between Trondheimsfjorden and Storfjorden. And regarding coopetition, no data evidence implies that coopetition occurs between the testbeds.

Research question 2:

What are the most significant drivers and barriers today for the testbeds and their impact for the further development of the testbeds?

As mentioned in the literature chapter drivers and barriers are something that makes other things progress, develop, or grow stronger and something that prevents something else from happening or makes it more difficult (Cambridge Dictionary, n.d.-c).

Barriers

Barriers have been coded to keywords. The keywords used most frequently are on the top, with a number indicating how many times it has been used.

One interesting discovery from the analysis was that the interested organization identified more barriers for the testbed than the testbeds themselves did. The reasons for this will be discussed in the Discussion chapter. And many of the barriers can also be seen as drivers, and vice versa.

Barriers	Description
Business model (9)	The most frequent keyword is business model or lack of a business model. All testbeds, except Horten, are developing the business plan. And the actors around (Authorities and interested organisations) confirm that there is no formal administration of the testbeds. It has been poorly organised on all the testbeds. No one has responsibility, no structure and no ownership structure. It is difficult to find an authoritative person in each testbed. Because it is important to have a business model that works, the barriers will come from a business perspective when introducing real-life aspects. There will then be many variables for which the testbeds must begin to prepare. There must be strong actors in the area who have financial indication and want to engage in development. It is difficult to find a good business model, the testbeds are an integral part of a larger system consisting of clusters, incubators, and projects.
Few users (7)	There has been less activity in the testbed (Horten) than first thought. The pandemic may have put a brake on the activity, but perhaps there weren't that many people interested in the testbeds. That there was too little volume and too few users in the local area. There was a lack of initiative by the actors and by the testbeds themselves. There are relatively few users in each testbed, especially in Horten. But also nationally. The environment around autonomy in Norway is small. Resulting in that a few people do many different things. Much is underfunded and understaffed, so the implementation did not go or is going as desired. And of the few actors that exist, many are involved in very similar projects (water buses), so there is a lack of diversity. Note: In Trondheim there has been a lot of testing activity with many different users.

Financing (6)	Getting funding for testbeds can be a challenge, as few are willing to invest. In Storfjorden, the testbed requires significant investments, but funding processes are slow and there are delays. This could make it difficult to maintain momentum in development. Local political financing requires meeting certain criteria to continue receiving funds. Additionally, Innovation Norway provides funds and requires research findings, leading to competition between testbeds and clusters. These challenges are difficult to change, but it's important to be aware of them. Financial constraints also affect clusters, who seek projects and results in their area instead of collaboration, making it challenging to collaborate across clusters. Unrealistic expectations are often associated with financing opportunities.
Regional competition (6)	A regional competition in Norway will inhibit collaboration and knowledge sharing. Artificial geographical limitations can arise, for example on a socially organized dimension of regions, counties, and municipalities. They have worked for political independence to ensure the right decisions for them. Examples of this could be road works or other political measures that create artificial borders. Too little activity can reduce the activity in other testbeds. Which in turn can create competition. Each testbed is fighting for the few users that exist. And thus, one looks inward and focus on your own. In Eastern Europe, there are affordable testbeds available that actors can rent, and then Norway loses the international competition. If there is a battle for position between the clusters and the universities, this will be like a district championship and not a world championship. Where Norway has a strengthened 'national team' and can compete internationally.
Learning and knowledge sharing (5)	The knowledge is not shared in a good way between the testbeds. There is little overview of what the different testbeds do. A platform is missing to collect experience data and build a structure around the autonomous projects in Norway. A somewhat interesting finding is that Haugalandet has not been in contact with other test beds to gain experience or guidance on how to establish and operate the test bed. Instead, they rely on local knowledge.

Geography (4)	The logistics and costs associated with transporting both goods and people can pose significant challenges in the field of geography. Scaling up and obtaining a high volume in the testbeds can also prove to be a daunting task. Furthermore, the distance between testbed locations can hinder collaboration and learning opportunities. In addition, the northern location of Norway and its harsh winter climate may limit outdoor activity and prompt researchers and practitioners to seek warmer climates abroad for testing purposes.
Synergy / coordination (4)	Lack of synergy effects between the testbeds. That the testbeds operate locally, and it will be a testbed for its own area. And they don't look up to see what the others are doing. Live in their own bubble and lack the overall picture. For Norway, as a small country, it is important to have a synergy effect. There will be too little coordination between the testbeds, and they do the same thing. Lacks sufficient exchange of information on a business level. This may be due to funding from the county, that the project should look useful and thus end up similar to other projects. There is a lack of a driving factor that is superior and a driving factor that says that they should collaborate and coordinate. There may be too many '3-headed trolls', who need help coordinating where to go.
Communication (3)	A lack of communication between industry and academia can cause misunderstandings and misinterpretations if there is poor or missing communication and information exchange with other testbeds and actors. That the testbed do not get to show and explain what actually exists in the testbed, and the testbeds are a national investment. (For Trondheimsfjorden, this is an important aspect they want to improve. Have good and clear communication externally). The actors may move elsewhere if they do not know the possibilities and features of the testbeds.
Continuity (2)	If there is a lack of continuity, the testbeds may not achieve their intended goals and could potentially end up being a one-time investment. The lack of effective management of long-term industrial investments is hindering the overall structural growth of the nation.
Catapult arrangement (2)	The catapult arrangement fails to create national collaboration. In the Trondheim area, there is a lack of a catapult centre. The arrangement is intended to increase activity in an area by reducing certain costs. A catapult arrangement can contribute to increasing the use of the testbed.

Respect (2)	It is important for testbeds to show respect and recognition towards each other without adopting a top-down attitude. Project ownership should be balanced among various university and research institutes involved in the projects. Without mutual respect, collaboration becomes challenging.
Operational value (2)	It is unclear if the testbeds are providing any operational benefits or if there has been an increase in activity since their implementation. Currently, there is doubt regarding the testbeds' significance, and their perceived value.
Culture (2)	Research culture can be problematic for the industry. Small and medium-sized companies have a completely different timeline and less financial framework than the research world. Research institutes have very established structures, and it can be challenging to turn around or change that culture.
Time perspective (2)	Due to limited resources and technological readiness, tasks may take longer than expected. Several actors may be to optimistic about new technology, and it may take a long time before that technology is ready for testing. In other words, it is very resource-demanding and complicated for a case or project to complete an autonomous vessel test alone. Better to have a limited problem where actors examine something specific in each case. And if there is a lack of a long-term aspect, the actors can become too time-optimistic and impatient.
Focus (1)	Trondheimsfjorden has a strong focus on research projects compared to industrial projects. It can be difficult for the industry to gain access. The testbeds must be able to offer services for both industry and academia.
Timing (1)	Funds are limited, and getting the product right regarding timing is challenging. Early out, there is little volume, late out, there is a lot of competition.
Capacity (1)	Lack of capacity. The need for capacity often challenges good intentions, especially for universities. The workload becomes too great for the staff.
Collaboration (1)	There is little or no collaboration between the testbeds, nor has it been observed by external companies.
Regulation (1)	The lack of regulations on testing new technology makes it difficult to tackle the challenges posed by it.
Technology costs (1)	Currently high costs for autonomy. Both investment and use of this type of technology.

Application processes-project start-up (1)	The application process can prove to be a challenging task. It is not uncommon to encounter inflexibility in the process, which can make it challenging to modify your plans. Additionally, the timeline from application submission to project implementation can be protracted. These circumstances apply to both state and academic applications.
Testing outside the testbeds (1)	Large projects often receive permission to conduct testing in a designated area, which is outside a testbed. The actors themselves find other solutions on how to handle and develop.
Sensors (1)	In Haugalandet, the industry itself will invest in sensors and measuring equipment. It can be challenging to create standardization with other testbeds. Whether the industry will actually pay for the equipment is currently unknown.
Negativity (1)	Haugalandet met some resistance and scepticism about the value of establishing a new testbed. Some believed that this existed before and questioned the operational value of the testbed.
Availability (1)	If the industry does not access the infrastructure easily, they will look for other solutions.
Standardization (1)	Lack of standardization between testbeds.

Drivers

Drivers has been coded to keywords. The keywords that were used most frequently is on the top with a number indicating how many this it has been used.

Drivers	Description
Industrial development (6)	Where the industry is, and where there is money, and where there is a separate topic being tested out, creates opportunities. Autonomy is perhaps more useful at sea than in other transport sectors. There are lower speeds, greater distances, and more visibility. If the testbeds manage to drive industrial development, they will become a natural meeting place and collaboration arena for the parties in academia, industry, and the authorities. Have an arena where new technology can be tested in real environments, where not only autonomy is improved, but also the development of measuring instruments and sensors. The testbeds are a natural starting point for investing actively in the logistics chain. Encourage collaboration and integration among value chains, business models, and logistics chains.
Ecosystem (6)	All testbeds are linked to a strong ecosystem. Trondheimsfjorden, with NTNU, SINTEF and the associated ecosystem, has a robust technology and development environment known nationally and internationally. The fjord is well-instrumented, and many different activities are going on. Storfjorden has a strong professional, academic and industrial environment, such as the Kongsberg group and large shipyards. Horten has many active partners in and near the testbed. Kongsberg and FFI (Norwegian Defense Research Establishment) are significant actors who actively use the testbed. Many large capital-strong companies around the testbed. Examples of this are Yara Birkeland and Asko Barger. With strong actors come benefits such as having access to an operations hall established by Kongsberg, which the University and other actors can use. Horten VTS is also operating in the area. Haugalandet is located in a strong maritime environment. They consist of large energy companies, shipping companies, subcontractors, Fjede VTS and public initiatives. The Norwegian Coastal Administration and the Norwegian Maritime Authority are located in Haugesund. It exists many other testbeds locally, can get synergies from them. Several actors want to use the testbeds actively in their business plans.

Collaboration (5)	Significant gains are predicted for the parties if they manage to collaborate on an operational level. With a focus on collaboration between the actors. The universities have clear prerequisites for establishing an organized collaboration. But collaboration with the industry can be more demanding. In Horten, the main collaboration for USN and nearby actors is to use the test bed to train seafarers, engineers in technology and sustainability and business traders. In the areas where there is a VTS area, it is easier to get the Coastal Administration active. Storfjorden is deeply committed to openness, collaboration, learning and knowledge sharing. Want an active site with a lot of activity and that their services are used.
Self-determination (4)	In all the testbeds there is a high degree of self-determination. As long as the actors follow the guidelines of the Norwegian Maritime Authority and the Coastal Administration, they can do everything themselves in the testbed.
Authorities (4)	The authorities want to improve maritime safety, reduce climate emissions, and have 24/7 operations. The testbeds are a good tool to find the technology the authority wants to focus on. The testbeds can help there. The maritime authorities are a vital driver of development. It is free to use services from the Norwegian Coastal Administration and the Norwegian Maritime Authority. They can contribute knowledge and ensure that the testing takes place within a safe framework.
Complementary (3)	Different testbeds test out different things. If they are complementary, the testbeds avoid a direct competitive situation. As long as the testbeds find their theme and specialisation, it will automatically create a drive in each testbed. For example, Horten focuses on operations, while Trondheim focuses more on technology development.
Costs (3)	The state has covered all equipment costs for the testbeds located in Trondheim and Storfjorden. In the remaining testbeds, the primary expenses are related to personnel. Currently, there are minimal or no costs for those using the testbeds.

Standardization (2)	The testbeds help develop standards and rules aimed at the EU and IMO. Have the same digital backbone in Norway. If there is standardization in the testbeds, it will be cheaper and easier for actors to test. If someone in Trondheim wants to test somewhere else, just need to send the sensor package and equipment package. The digital backbone and infrastructure are the same in each testbed.
Positivity (2)	There is a lot of positive goodwill towards the testbeds. And the authorities are positive and helpful.
Catapult arrangement (2)	The arrangement manages and creates local cooperation and progress. Haugalandet is closely linked to the catapult centre, which finances pilot projects that can be used in the testbeds.
Geography (2)	Norwegian geography and few people can also be a driver. Has already been achieved a lot of autonomy in Norway. There are short approaches and little bureaucracy compared to larger countries, and it is easier to change the Norwegian rules within the 12 nm zone. There are areas with challenging weather conditions, great depths, trafficked areas and calm waters in the various testbeds.
Technological interest and profit (1)	Activity in the area and creating new services for the world, using the testbeds to obtain more funds and develop the technological situation and the interest around it. The industry then has an area where they can create industrialization and export goods. An important driver for the industry.
Framework (1)	The testbeds have a framework in place that provides actors with the basic services required for testing. This eliminates the need for creating new applications with different vessels or variants. Additionally, electronic navigational guides with fixed options are available for everyone to download and use at no additional cost.
Data streaming (1)	There are different services that to flow data through. For example Clarify.
Time perspective (1)	There are long-term plans for all the testbeds, considering the value chain and new green technology.

Specialization (1)	Horten is actively targeting control centres for the training and certification of operators. The industry is there as an important actor, and it can become a good source of income for the testbed.
Varity (1)	Testbeds is a partner in many projects in many different segments.
Students (1)	Important arena for students. Autodrome, a student competition, is organized in Horten. Students get good opportunities to complete current bachelor's and master's theses in the testbeds and get a good and relevant education.

Summary research questions 2.

Top five drivers and barriers

	Drivers	**Barriers**
1	Industrial development	Lack of a business model
2	Eco-system	Few users
3	Collaboration	Financing
4	Self-determination	Reginal Competition
5	Authorities	Learning and knowledge sharing

Table 6: Most significate drivers and barriers. Made by author.

In the analyse, 18 different categories for drivers were identified and 26 categorise for barriers, indicating that the testbeds are facing more challenges than opportunities. Many of the barriers are connected to the lack of a business plan, affecting learning, collaboration, and overall business performance. Lack of business plan is the most significant impact on the future development of the testbeds to reach their own goals and the authorities' objectives.

Research question 3:

How can the learning be improved between the testbeds?

During the interview and data collection, it became clear that a connection link was needed between the different testbeds to improve the learning and exchange of lessons learned. A link where collaboration, cooperation, and learning could occur. The most feasible solution suggested was a web platform that would provide information about each testbed and

facilitate learning from them. However, there were differing opinions on the platform's design, including the amount of content it should feature, who would be responsible for it, and how it would ensure users' privacy. Because of that, these details need careful consideration for designing a web platform.

It is not necessarily that these are the testbeds that operate the web portal. An interested organization or a government company could do it, but there were no strong findings in the data to say precisely. A few of the participant's organizations already have some solutions under development, and of special interest was Testination, develop by Ocean Autonomy Center. This website could be a starting point for this web platform.

Another important point is that the testbeds themselves must invest in operating this platform, provide the information, and use it as an active tool in day-to-day operation. But the workload must be low because there are a few people with much responsibility in and around the testbeds. The web platform needs to be manageable.

This approach to promoting learning between the testbed with a web platform is a data-driven category, which is very interesting and relevant since such a solution was often mentioned in the interviews.

A participant from Haugalandet shared an interesting insight about a web platform that was attempted to be established in Rogaland county municipality. The goal was to link all county testbeds together on the same platform, but the project became too complex and was never fully completed. An attempt was made to reach out to the municipality for a comment on why it was not finished, but unfortunately, they never responded.

Discussion

The discussion chapter will begin with research question 1, then research question 2 and followed by research question 3. At the end a small discussion regarding who can benefit from the findings and can the findings be used in the future.

Research questions 1

IMPELLO identified different success factors for the testbeds (IMPELLO, 2020). A testbed is likely to succeed if it meets all these criteria. To assess the success of current testbeds, a table has been provided below, which presents the results of the data analysis. The table examines whether any of the testbeds were successful in achieving specific factors. The green color indicates a clear finding in the data. The amber color indicates medium findings in the data. The red color indicates no clear findings in the data.

	Trondheimsfjorden	Storfjorden	Horten	Haugalandet
Clear objective				
Clear ownership				
Full-time resources				
Business model and budget				
Plan for resource use and infrastructure				
Good collaborative climate (Locally)				
Involvement of local authorities in regulations and legislative changes				
Involvement of the eco community				
Communication				
Local users as active participants and testers				

Table 7: Success criteria. Made by author

IMPELLOs description of the success criteria's:

Clear objective:	With a clear purpose, collaboration, investment, and organization can become more structured. However, note that the various parties often have different purposes and needs in the testbed. Therefore, it is important to ensure that these goals do not conflict with each other.
Clear ownership:	To ensure progress and development, having clear ownership of the testbed is crucial. The progress of the testbed as an entity relies on the responsibility and drive of its owner.
Full-time resources:	To make progress and develop effectively, it is important to have dedicated resources solely focused on the task of managing the testbed. Having full-time resources who can operate and develop the physical arena and all related aspects is critical for both start-ups and ongoing operation of testbeds. Just like with ownership, having these resources is crucial.
Business model and budget:	Having a well-planned business model and predicting demand is crucial for securing proper funding and making wise investment decisions.
Plan for resource use and infrastructure:	As with any investment, it is important to have a common understanding of investment needs.
Good collaborative climate (locally):	By working together in testbeds, the parties strive to achieve a greater benefit than what they could accomplish individually. Trust and collaboration are essential for joint progress, which goes beyond the commercial advantages for each participant. It is important for all participants to clearly understand their benefits and purpose for joining.
Involvement of local authorities around regulations and legislative changes:	When testing new technology, authorities and private actors need good communication to adjust regulatory frameworks. This is especially important for groundbreaking technology like autonomy. Testbeds can help identify necessary regulatory changes. Local authorities have a key role in facilitating and communicating these changes for technology applications.
Involvement of the eco-community:	The viability and demand of products and technology are evaluated in the business world. There are various ways for business actors to enter a test arena, such as through funding, as a user of the testbeds, or as customers of the technology being tested.
Communication:	To attract international actors to the local infrastructure, a testbed must have effective marketing and external communication. This is crucial to ensure optimal utilization and activity in the testbed. However, reaching out to companies can be challenging.
Local users as active participants and testers:	A testbed can have significant impacts on the local community. By engaging local companies and individuals, one can gain a better understanding of the test arena and test more practical scenarios that can benefit the local population. For instance, Norefjell is an excellent example of a testbed that actively involves the local population in testing mobility solutions for seasonal attractions.

The table outlines the current status of the testbeds in Norway. This information has been carefully compiled and presented to provide a clear overview of the current situation. All the testbeds have good potential to become a success.

Lessons learned

Trondheimsfjorden had a lesson learned with communication, to avoid misconceptions and misunderstanding, and now prioritize good communication. The testbeds in Gothenburg, Sweden, faced similar problems with communication. Their improvement was to centralize their communication efforts regarding its testbeds to promote the local opportunities available to a broader audience (IMPELLO, 2020).

During an interview, it was suggested that maritime testbeds could benefit from the lessons learned from land-based testbeds for autonomous shuttlebuses. Since there are many similar projects for autonomous ferries being tested in the maritime testbeds. In 2019, there were 19 projects and activities related to small autonomous passenger ferries in Norway (Tannum & Ulvensøen, 2019). The land-based and sea-based vehicles have a lot of the same technological issues. The challenges encountered in both testbeds share similarities, which allows the lessons learned to be applied in both types of testbeds.

It is important to consider the benefit to society early in the project phase, i.e., work for a seamless transport chain. Where hubs such as quays, terminals and ports are included in the early development phase. The actors must design the tests according to this need. The solution serves user-friendliness and benefits the society (Lervåg et al., 2018).

There have been many lessons learned from technical immaturity. For autonomous buses, they started with immature technology in advanced environments. There they narrowed it down to specific aspects and began to use 'use case' methodology more actively. When designing projects, it is crucial to consider the entire value chain and use "use case" methodology (Anda, 2004).

The project timeline was much longer than initially planned, and many actors may lack experience. Many actors have to go through phases in order to develop quickly enough. If one of them is not in phase, i.e. does not have time or capacity, then time is spent on organizational matters. And the security clearance took a long time. For a 2-year project,

getting all permits in place can take up to 2 years. Both administrative, organizational, and technological things make it difficult to move quickly. Many of the actors involved in autonomy are inexperienced (Lervåg, 2020).
A quote from the participant that explains the problem in a good way. "*It's not Boeing or Airbus that makes drones; it's other companies that have never made a drone before. They must learn to fly before they can make an autonomous system*".

Another important lesson learned were that the actors had to communicate with more actors than first thought. Having a collaborative forum is important, and there is high acceptance of autonomy from the public (Lervåg, 2020).

In 2019 Roche Cerasi, 2019, performed a national study of user perspective of autonomous vehicle. The study reported a positive acceptance for the use for autonomous vehicles. The passenger is overall satisfied and feels safe.

The testbed should make good use of the lessons learned theory. Since projects are something the testbeds have to deal with on a daily basis. Zambruksi, (2008), argues that to improve productivity and efficiency, handling lessons learned are valuable and helpful.

Collaboration and learning with other testbeds

Based on current findings, there is little collaboration between the testbeds. And this finding is supported by Danish Technological Institute (2020). According to their report, none of the ask testbeds had prior experience with legal forms of collaboration. However, the precondition for collaboration is present. The Nordic innovation infrastructure is exceptional in effectively incorporating new technologies into commercial use. This is due to the advanced technology used in the testbeds, which enables the identification and adoption of research and new technologies (Plamberg, 2019). There are several challenges to renewing technology innovation infrastructure and competitiveness. Competent, skilled employees, new technology trends, and industry demand drive technological renewal. However, it is not just a bottom-up process. It must occur within the systemic framework of governance and business models (Jacobsen, 2020).

Based on the findings, it appears that the testbeds have limited collaboration and learning opportunities. This is due to the organizers' emphasis on creating a solid business plan before initiating any collaboration, and it is probably a strategically smart decision the

organizers. It is recommended to wait until the business plan is finalized before starting any collaboration. Organizations with collaboration success are explicit about what they want to achieve and how collaborative effort can help advance those goals and before collaborating, it is important to evaluate the situation, comprehend the desires and incentives of each participant, and determine potential courses of action and the organization's roles (Bartczak, 2015). Collaboration among the testbeds requires a rational evaluation of their utility. Collaboration can be sustained if the parties involved feel that their relationship is clear, beneficial, and well-organized (Bachmann & Zaheer, 2006). Research indicates that trust is a crucial factor in the success of collaborative efforts (Lane & Bachmann, 1996).

Research questions 2

To ensure a concise conclusion, only the most significant barriers will be discussed.

One observation during the analysis was that the interested organizations and clusters provided much more barriers for the testbeds than the testbeds themselves. This could be that the testbeds participants didn't want to share the total truth or that don't have much knowledge about the topic (Alvesson, 2011). Another possible reason is that critical observations are easier to make by a third person who is somewhat detached from the situation (Mykland, 2011).

Regarding the findings is the lack of a proper business plan the biggest barriers for the testbeds. Business competence needs to be developed for avoiding or handle other given barriers. This is supported by the literature (Jacobsen, 2020), (Lervåg, 2020), (Region Blekinge, 2022), (IMPELLO, 2020).

A barrier that was common is that few users. But according to Nesta, testbeds should limit the number of active partners to ensure a simple organization and distribution of roles (NESTA, 2019). Few users could be a barrier, but it increases the opportunity to develop a good relationship with the users who are active.

According to the findings, it has been difficult to obtain funding. How the testbeds should get funding should not be speculated here. But when funding is in place, NESTA recommends a step-by-step financing plan and contacting other testbeds to help plan investment needs and resource use (NESTA, 2019).

A few participants had some tacit knowledge of regional competition in Norway, but there was a lack of credible sources to verify such knowledge. Anyway, a very strong indication is that a regional competition could hinder development. To prevent competition, it is crucial to establish effective collaboration (Porter & Van der Linde, 2000), (Jacobsen & Thorsvik, 2019).

There is not much literature on barriers and drivers for testbeds, but a new report from Region Blekinge (2022) presents some obstacles for testbeds. And their main findings were: Testbeds are an ambiguous concept and an actual need for shared resources must exist. Testbeds need a solid business model to survive and thrive. A testbed community does not grow without help, a dedicated person is needed to foster relationships, organize community activities and create a shared sense of belonging among members. If every city acts as an island, few interactions between cities that have a testbed is an obstacle (Region Blekinge, 2022). Many of these findings conform with the findings in this thesis.

The report also included some recommendations for the testbeds. Complete a comprehensive testbed inventory of the region. Develop more expert resource lists, testbeds provide a physical space with shared equipment, and knowing who can help is equally as important as knowing what tools to use. Foster a community testbed forum. Join forces with other regional testbeds efforts. Develop expertise in “testbed-as-a-service” (Region Blekinge, 2022).

Findings indicate that there are internal barriers linked to lack of legitimacy (Greer & Bruno, 1996) and lack of commitment (Carter & Dresner, 2001). To which extent is not properly documented. No finding indicates that the testbeds have experience any external barriers stated in the literature review.

Research question 3

Realizing the importance of a learning platform can be a significant step in achieving the goals and fulfilling the testbed's potential. By utilizing the resources and tools available, the testbeds can enhance knowledge and skills and open up new opportunities for growth and success. A learning platform can provide the support and guidance the testbeds need to reach their full potential. Real life testing in complex environment and with real users contributes to identify limitations and need for further developments in terms of technological, legal,

organizational, and societal aspects. Furthermore, it points out best practice and provides experience needed to succeed in a future transport system (Lervåg, 2020).

The region of Blekinge suggested some recommendations for the future of testbeds in the area. The proposal is to create a community forum for testbeds, improve their connectivity, and enhance their value as teaching laboratories. These recommendations have high strategic importance (Region Blekinge, 2022).

Although there is no definitive guide in the data collection on how a web platform should be structured, valuable insight can be gleaned from existing literature and published reports regarding important components that should be included.

It is highlighted that a forum should use practice-based learning (Region Bleking, 2022) Practice-based learning is connected to the experiences gained through participation in a project, either through direct involvement or observation (Higgs, 2012). Further could the *learning loop* be used as the steps in learning (Milton, 2010). One a such web platform will the explicit knowledge gather. As it is easier to share and use by others (Polanyi, 2000). Such a web platform can strengthen a learning community where the testbeds can complement goals and objectives (Voosen, 2008), and create a synergy effect in connection with a cooperative learning approach (Johnson, 2002).

United Nations Secretariat of the Internet Governance Forum (IGF) has provided a platform to exchange experiences in addressing Internet policy issues. The objective is not to develop new policies or practices, but rather to share positive and negative experiences, collect existing good practices, and flag challenges that require additional multistakeholder dialogue and/or require the attention of authorities. A coordinating team manages the forum, while the participants share their experiences (IGF, 2020). This structure corresponds well with the findings in the thesis. That the testbeds do not operate the web platform but by a neutral third party, who is the coordinator and responsible for the web platform. This web platform could lead to a *digital testbed cluster* (Nasiru & Radicic, 2019), that could promote collaboration and value increasing (Porter, 1998). But it is also reasonable to think that coopetition could occur, since coopetition is often used by actors in the technological field with long-term perspectives (Brandenburger & Nalebuff, 2011).

It is important to point out that such an attempt was tried, but it did not work due to unclear structure and ownership in those testbeds. The business model must be present and active before such a web platform can be active.

Findings summary. This thesis goes through all the testbeds and surveys the current situation. It can be useful for authorities and initiative-takers who wonder what the situation is now. The drivers and the barriers findings can help the testbeds avoid the future barriers and cultivate the drivers. Interest organizations and testbeds can benefit from the findings related to a web platform that can improve learning between the testbeds. The literature on maritime testbeds may be limited, but the literature that has been found is generalized with the research findings.

Limitations

Discussion of the research quality (validity and reliability).

Reliability

In qualitative research, the quality of the results is connected to the researcher's capacity to analyze how the research process influenced the outcomes. This involves reflecting on the interaction between the researcher and the presented results. (Hammersley et al., 1987). Reflexivity is when the researcher utilizes their knowledge of interview situations to reveal and clarify how the situation is affected by being studied (Jacobsen, 2015). To ensure the credibility of a thesis, it is important for the researcher to clearly explain their role in the research situation. The researcher's openness and reflection enhance the strength of the research credibility (Mays & Pope, 2000).

One of the challenges is to ensure that the assignment text is explicit, clearly, and simply written. Credibility is linked to the researcher's ability to make things explicit (Jacobsen, 2015). In assessing the quality of research, transparency plays a crucial role for readers to evaluate the methods used. This allows for a more comprehensive discourse, enabling others to provide critical, complementary, or alternative perspectives, which can contribute to the further development of knowledge in the field (Mays & Pope, 2000). A challenge has been producing an explicit and simply written text with good credibility, where transparency is clear about the methods used. And there is a logical thread throughout the text. This thesis consists of a lot of text and information. It has therefore been very time-

consuming and challenging to create the logical thread. But systematic work has been tried to make the best possible credibility.

The analysis of data is a crucial factor in ensuring reliability. However, there may be some level of discretion involved in categorizing and sorting the data, which could result in units being randomly placed in different categories. This can lead to poor reliability, especially when the analysis is done individually. To address this, the researcher can repeat the categorization process or have an independent researcher cross-check the content. (Jacobsen, 2015). To ensure reliability, the researcher conducted the analysis in this thesis twice. It was not possible to contact another independent researcher to repeat the analysis. However, the extent to which this approach enhances reliability is uncertain.

External validity

External validity refers to the extent to which research findings can be applied to a broader context, leading to generalizations (Krippendorf, 2019), (Kvale & Brinkmann, 2015). Qualitative methods can reveal underlying phenomena and establish causal relationships, but generalizing findings from a small sample to a larger population is challenging. The sample may not accurately represent the entire population (Kvale & Brinkmann, 2015). One benefit of this thesis is that only a limited number of maritime testbeds are available in Norway, making it possible to reach the entire population. To answer the research questions, finding suitable participants with relevant information was crucial. Having a diverse range of data was essential for this purpose. Therefore, participants that represented the range of the thesis were chosen (The authorities, clusters, and interest organizations). But this entails that it may be challenging to argue that the findings reflect typical or common occurrences. Instead, the researcher must claim that the study encompasses the entire breadth of the phenomenon being investigated (Jacobsen, 2015). It is in the researcher’s own opinion and discretion that the spread is reasonable. Of course, one could argue to include other types of testbeds, to present their design, learning etc. But for this thesis, it was chosen to narrow it down to only the maritime testbeds because of limited time and resources.

Internal validity

Internal validity questions whether the researcher's description of reality actually corresponds to reality (Jacobsen) The researcher's goal is to describe a reality that cannot be directly observed. There are three key questions that the researcher must ask. Firstly, have the

study subjects provided an accurate description of their reality? Secondly, is the researcher's interpretation of the data correct? Lastly, do the findings and conclusions accurately reflect reality? (Kvale & Brinkmann, 2015).

To ensure good internal validity of the thesis, it's crucial that the participant accurately represents reality (Jacobsen, 2015). Researchers using qualitative data collection, particularly interviews, must avoid assuming that what people say and do always reflects reality. People may be unable or unwilling to reveal the truth, and it may be difficult to determine if the reality presented by those being studied is genuine (Alvesson, 2011). It is necessary to acknowledge that the researcher displayed a naive attitude during the interviews. It is possible to argue that the researcher should have posed more probing questions in order to uncover the underlying reasons for the different statements. But it was important for the researcher to have a pleasant atmosphere in the interview where the participant could speak freely about their opinions. Furthermore, all participants are highly-status individuals with substantial education, experience, and knowledge. Therefore, their responses were believed to be truthful and sincere, not outright lies or misconceptions. No particular finding in the analysis indicates that anyone has lied or made false claims.

During the data analysis process, researchers simplify and systematize details while adding abstract elements. However, this can lead to a disconnection from the original data sources and an increased risk of personal biases and opinions being incorporated into the results. Therefore, it's crucial to be aware of this potential bias and work to avoid it in order to ensure accurate and unbiased findings (Grønmo, 2020). To prevent this issue, it's important to ensure authenticity. The researcher can validate the findings by confronting them with the participants to establish credibility and that the participant recognizes themself in the presented results. They can validate the findings or give feedback (Lincol & Guba, 1985). The findings in the thesis were not reviewed by anyone other than the researcher and supervisor before submission. This means that the validity of the findings is low in that particular context.

To ensure the accuracy of the analysis, the next step is to validate the categories and events through critical discussion. This helps to confirm that the data is accurately categorized. One approach is to have a second researcher conduct an independent analysis and compare the results for consensus. Another method is to test the impact of changing categories and events on the outcome of the analysis and compare the results. If there is a

significant change in the result, it could indicate inadequate validation of the categories and events (Jacobsen, 2015). The last method has been used in this thesis, and there were no significant changes in the findings. Qualitative analysis is effective in describing the mechanisms that connect categories or events. If co-variation is proven between the categories and it is argued that there is a connection with the literature, such conclusions should never be taken for granted (Jacobsen, 2015). It's important to evaluate the thesis's discussion on the connection critically. It's worth noting that many of the mechanisms presented are based on found literature. If different keywords or literature were utilized, other sources could have influenced the discussion and the overall context may have been altered.

To ensure accurate results, it is important to validate them against reality. One effective method is triangulation, which involves examining the same problem from multiple methodological angles. If these different methods produce consistent results, it is strong evidence that the results are valid (Creswell & Miller, 2000). A simpler way to ensure validity is to compare the results with other research articles or reports. This can strengthen the validity of the findings, but it does not necessarily mean that they are true (Jacobsen, 2015). It has been difficult to verify all data related to maritime testbeds due to the limited number of reports available. However, the literature that has been found suggests that the results are valid. Nonetheless, there are no convincing arguments to support the extent to which these results reflect reality.

Conclusion

The main findings of **research question 1** are that the testbeds today have little or no organization structure in the testbeds. Testbeds has, until now, been used as a tool to simplify testing. There is a lot of development in establishing a business plan, so this finding represents the current situation and will not be a generalization in the future.
Each testbed is committed to achieving the goals set by the authorities, but they have different structures and motivations to achieve them. For example, the Trondheimsfjorden testbed is dedicated to testing and validating/verifying new technology. Storfjorden provides a quote "laboratory" for local shipyards and stakeholders and free sensor data. The Horten testbed aims to automate the entire value chain. Finally, the Haugalandet testbed focuses on the offshore segment. Although the situation is more complex, these are the key highlights located from the analyzing.

Through Social Network analysis, it was discovered that there has been limited collaboration and knowledge sharing among the various testbeds. The key insight revealed that the process of establishing these testbeds as independent organizations has been more difficult than anticipated. Without a clear organizational structure, collaboration and the sharing of ideas is hindered. Despite this, all the testbeds are positive for collaboration and exchanging learning effectively. No instances of coopetition were detected.

The testbeds did not yield many direct findings related to lessons learned. The most crucial takeaway is the importance of effective communication, both externally and internally within the testbed. The second finding is that projects often take longer than anticipated, making it difficult to maintain momentum. Lastly, it is essential to specialize in the support structure of autonomous vessels. Horten is focusing on developing the control center that will manage these vessels.

Research question 2 addressed the main drivers and barriers and their impact on future development of the testbeds.
The most important drivers that were mentioned the most times during the interviews are:

- The industrial development for the testbeds
- The ecosystem around the testbeds
- Collaboration with local actors and other testbeds

- A high degree of self-determination in the testbeds and,
- Proactive authorities

Based on this, the testbeds can be the link between the local ecosystem that works together for industrial development and where new regulations can be developed. Moreover, with a high level of self-determination, the actors have good opportunities to conduct the testing in a safe environment.

The most important barriers that were mentioned the most times during the interviews are:

- Lack of a business model.
- Few users in the automation segment.
- Challenging financing.
- Regional competition.
- Lack of learning and knowledge sharing.

In order to advance, it is crucial to establish a comprehensive and robust business model. While the limited number of users cannot be altered, the testbeds should not compete for the same existing users to prevent complications. Obtaining funding can be difficult and testbeds should be careful with handling the given/earned funds. To prevent regional competition, testbeds must stay informed about what's happening in other testbeds. If two testbeds begin the same operation, it could lead to unnecessary competition. Currently, there is no effective way to share knowledge and facilitate learning. The following research question explores which collaborative method can enhance learning among testbeds.

The **research question 3** investigated how the learning can be improved between the testbeds. A short summary is that a web platform, with basic information about the testbeds, guidelines, project insight and where learning and lessons learned could be uploaded by the testbeds themselves. The literature also support the proposal of having a web portal or forum to increase learning but also collaboration.

During the interview, some questions in the interview guide were difficult to answer, resulting in unequal coverage of the thesis objectives. For instance, there was insufficient data on the quantity and types of projects in each testbed, and no benchmarks were mapped.

Additionally, no cases of coopetition were observed. As a result, some of the thesis objective remains unanswered. But data were collected on various other aspects, including the learning and collaboration situation, to gain insights into the actual conditions. Additionally, drivers and barriers were identified that can provide valuable information for future development. To improve the learning between the testbeds, a web platform is argued to be the best solution. Creating a web platform could enhance learning between the testbeds if correctly executed.

By using established research methods this thesis has explored an unknown territory. The empiricism that has been collected has been interpreted and put into a larger framework of understanding to give meaning. With recontextualization method, the context has been transferred to another to create new knowledge. This thesis has new and significant information on the nature of learning and collaboration in the testbeds. To enhance these processes, a web portal has been documented as most valuable in improving learning and collaboration.

The Norwegian authorities, have clear objectives for adopting more environmentally friendly, intelligent, and green innovative approaches. And for the maritime sector, this is through green innovations. The testbeds have clear prerequisites for being essential in reaching these targets. However, some progress is still required before the testbeds can realize their maximum potential. The testbeds are valuable for testing, but they face obstacles in becoming active contributors to green innovation and the green shift. More barriers are discovered than drivers, and there is a lack of collaboration and learning between testbeds. Despite this, the potential for testbeds to drive change is significant and ongoing development should continue.

Issues for further research

An interesting research topic concerning this subject is identifying the collaboration and learning of land-based testbeds and comparing them to the collaboration and learning of sea-based testbeds. This way, one could easier identify the connection between collaboration and learning. The same kind of research should be done to compare land-based testbeds and air-based testbeds. The effect of collaboration and learning applies to both land-based and air-based testbeds.

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Appendices

Appendix 1: Interview guide in Norwegian

Målsetting og organisering – og intro til respondenten:

Kan du si litt kort om hva slags bakgrunn du har, og din rolle i testområdet.

Hva er den/de største motivasjonene til å ha et aktivt testområde?
(Inntekt, lokal utvikling, innovasjonsutvikling)

Hva ønsker dere å oppnå med testområdet?
(Visjon, mål)

Organisering

Hvordan er testområdet organisert, hvem har ledelsen?
(Organisasjonskart, avtale om samarbeid)

Har dere partnere eller underleverandører som bidrar til å levere?

Hva er tidsperspektivet for testområdet?

Forretningsmodell

Hvilken målgruppe har dere, hvem er kundene?
(Nisjemarked, massemarked, geografisk definert marked, målgruppe)

Hva er målgruppen mest opptatt av?
(Forbered ytelse, redusere kostnader, skape ny teknologi)

Hvilke konkrete tjenester tilbyr dere?
(Evaluere løsninger, vedlikehold, R&D)

Gjennom hvilke kanaler treffer dere kundesegmentet/aktørene?
(Oppmerksomhet, markedsføring, kommunikasjonsveier)

Hvordan tjener dere penger?
(Abonnement, per. Prosjekt, statlig støttet)

Hvilke konkrete prosjekter har dere i gang på nåværende tidspunkt?
(autonome fartøy, e-navigasjon)

Hva er deres største kostnader?
(Faste kostnader, variable kostnader)

Drivere og barrierer for suksess

Har du vært en innovativ tilnærming eller ny arbeidspraksis etter start av testområde som har blitt fanget opp og gjenbrukt flere ganger?

Hvordan er myndiggjøringen (selvbestemmelsen) fordelt i testområde?
(Tillit, finansiering, gjennomførbarhet, og plassering)

Hva er de viktigste suksessfaktorene for dere for å lykkes med målsettingene?

Hva er den/de største utfordringene å ha et aktivt testområde for å nå målsettingene?

Noen erfaringer knyttet til etablering og drift av testområdet

- Ting som var lurt å gjøre
- Ting som ikke var lurt/burde vært unngått eller gjort annerledes
  (Hvordan løste dere problemet, etterpå klok)

Samarbeid og læring:

I hvor stor grad samarbeider dere med andre testområder?
(Konkurranse, forretningshemmeligheter, **læring**, samarbeid med konkurrerende bedrift, IALA test prosedyrer, felles prosedyrer)

Hvordan deler/formidler dere kunnskap om arbeidet og resultatene i testområdet, og hvem deler dere med?
(lokale prosedyrer)

Hvilke forhold hos dere bidrar til å fremme deling av kunnskap og erfaring med andre testområder?

Hvilke forhold bidrar til å hemme slik kunnskapsdeling?

Hvis tid, respondens personlige mening:

Er det andre forhold som er kjent for å kunne hemme eller fremme samarbeid på operasjonelt nivå?

Hva er dine tanker om hva som kan gjøres annerledes?

Appendix 2: Request for participation in research project

Background and purpose

The purpose of this project is to gain understanding of the lessons learned in Norwegian testbeds. By testbeds are meant the geographic area where testing of new technology is conducted, by the approval from the authorities such as the Norwegian Maritime Authority and The Norwegian Costal Administration. You have been asked to participate is this study, as part of a sample that seeks to represent the key stakeholders of the testbeds. This research is part of a Master Thesis project at USN – Vestfold.

What does participation is the project imply?

Participation will involve an interview of approximately 25-30 min duration. The interviews will be voice recorded and the researcher may take notes. Data will be collected on demographical and professional details. Further, the interview seeks to elaborate on how testbed is operated, the collaboration structure, lesson learned, and the how the industry perceived value of published reports.

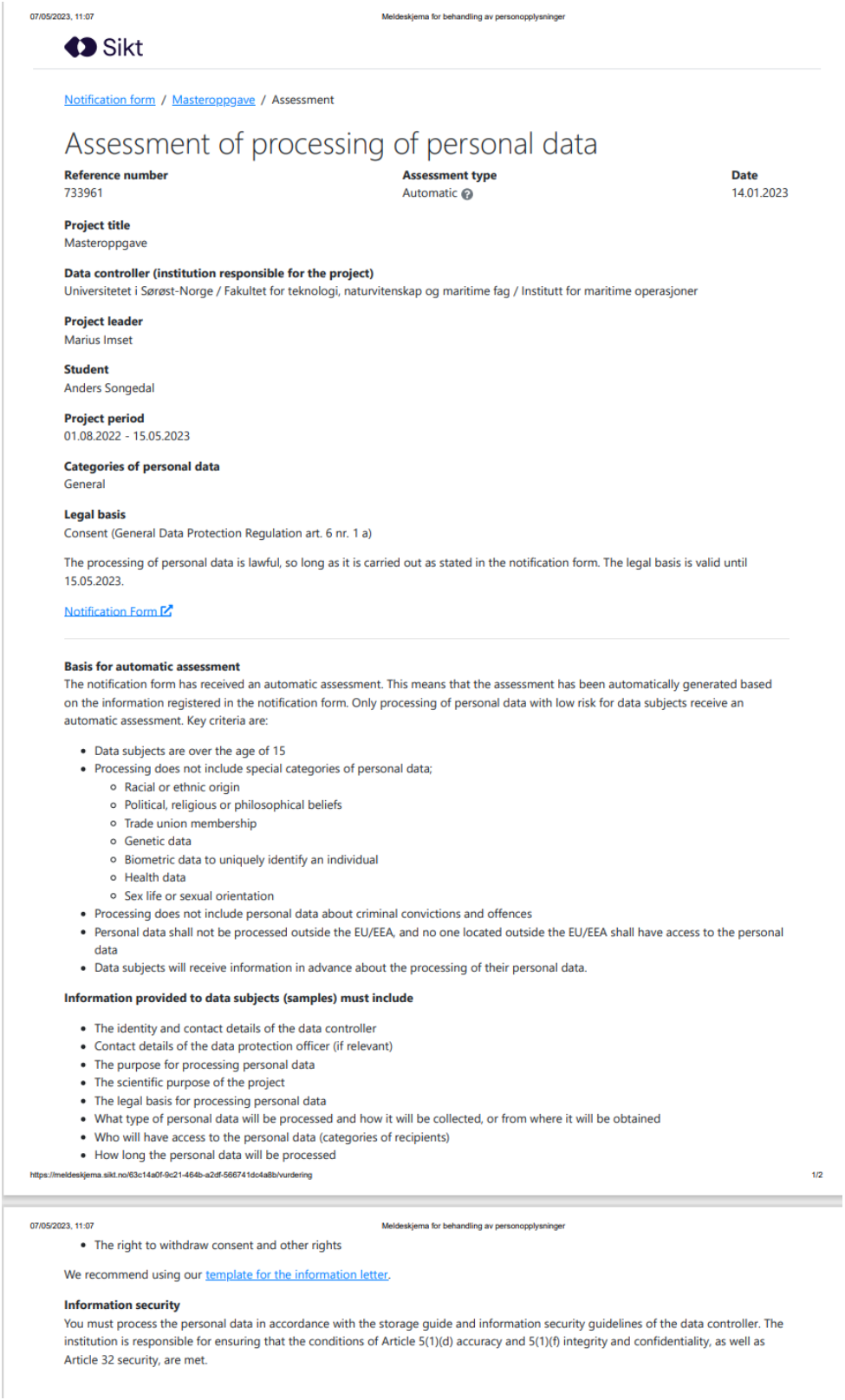
What will happen to the information about you?

All personal data will be treated confidentially and all information from the interviews will be anonymized. Only the student and supervisor will have access to the data and voice recordings. The data and voice recordings will be safely and securely stored. You, the participant, will not be recognizable in the publication. The project is scheduled to completion by May 2023. At that point, all voice recordings will have been deleted.

Voluntary participation

It is voluntary to participate in the project. You can at any time during the interview, and as long as your personal data is being processed, choose to withdraw your consent without stating any reason. If you decide to withdraw, all your personal data will be deleted and excluded from the research project.

Appendix 3: NSD approval



Sikt

Notification form / Masteroppgave / Assessment

Assessment of processing of personal data

Reference number
733961

Assessment type
Automatic

Date
14.01.2023

Project title
Masteroppgave

Data controller (institution responsible for the project)
Universitetet i Sørøst-Norge / Fakultet for teknologi, naturvitenskap og maritime fag / Institutt for maritime operasjoner

Project leader
Marius Imset

Student
Anders Songedal

Project period
01.08.2022 - 15.05.2023

Categories of personal data
General

Legal basis
Consent (General Data Protection Regulation art. 6 nr. 1 a)

The processing of personal data is lawful, so long as it is carried out as stated in the notification form. The legal basis is valid until 15.05.2023.

Notification Form

Basis for automatic assessment
The notification form has received an automatic assessment. This means that the assessment has been automatically generated based on the information registered in the notification form. Only processing of personal data with low risk for data subjects receive an automatic assessment. Key criteria are:

- Data subjects are over the age of 15
- Processing does not include special categories of personal data;
  - Racial or ethnic origin
  - Political, religious or philosophical beliefs
  - Trade union membership
  - Genetic data
  - Biometric data to uniquely identify an individual
  - Health data
  - Sex life or sexual orientation
- Processing does not include personal data about criminal convictions and offences
- Personal data shall not be processed outside the EU/EEA, and no one located outside the EU/EEA shall have access to the personal data
- Data subjects will receive information in advance about the processing of their personal data.

Information provided to data subjects (samples) must include

- The identity and contact details of the data controller
- Contact details of the data protection officer (if relevant)
- The purpose for processing personal data
- The scientific purpose of the project
- The legal basis for processing personal data
- What type of personal data will be processed and how it will be collected, or from where it will be obtained
- Who will have access to the personal data (categories of recipients)
- How long the personal data will be processed

- The right to withdraw consent and other rights

We recommend using our template for the information letter.

Information security
You must process the personal data in accordance with the storage guide and information security guidelines of the data controller. The institution is responsible for ensuring that the conditions of Article 5(1)(d) accuracy and 5(1)(f) integrity and confidentiality, as well as Article 32 security, are met.