Report

Fostering alternative fuels in Norwegian ports: does public policy address the challenges?

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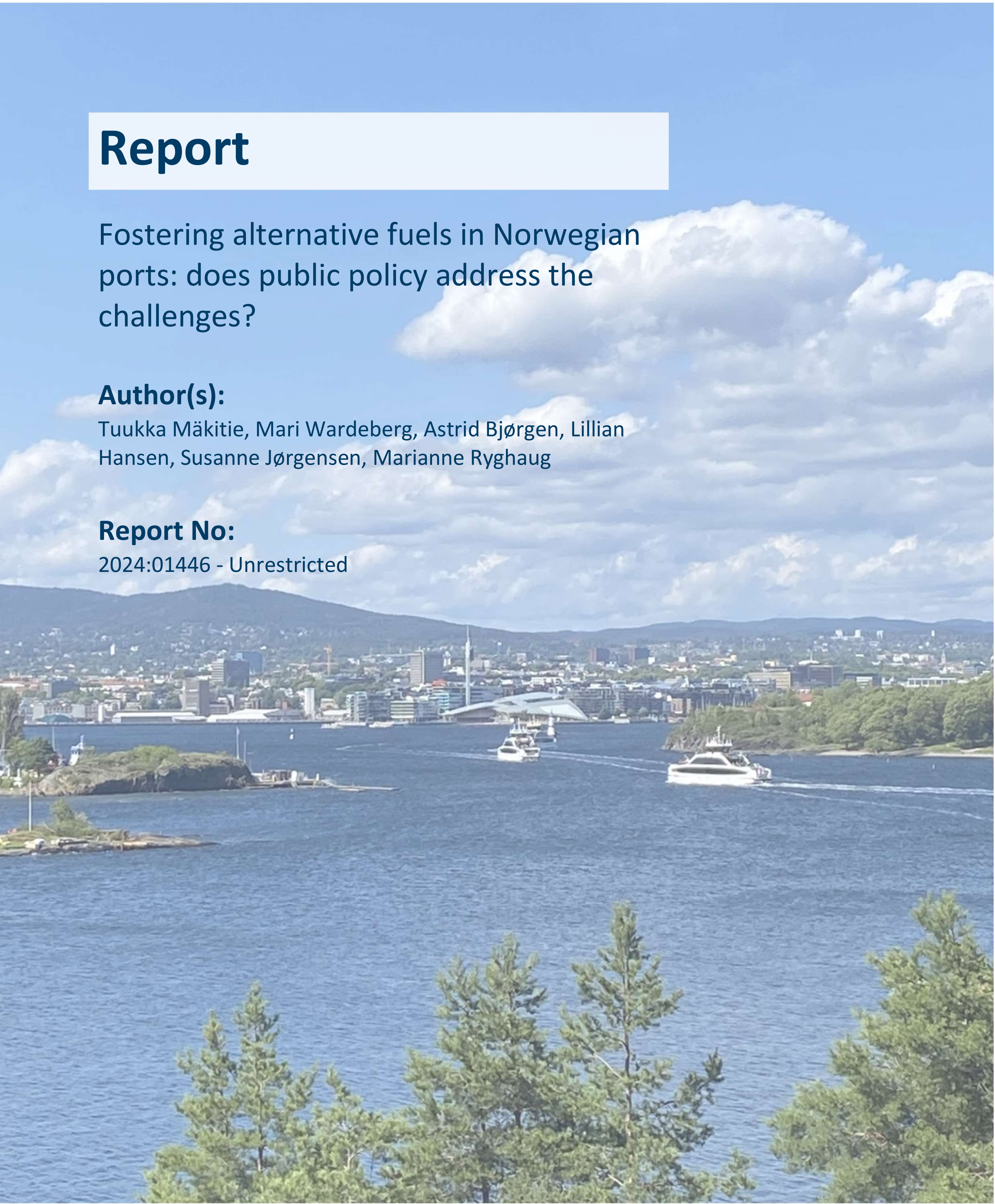
Report No:

2024:01446 - Unrestricted



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KEYWORDS
Ports
Alternative fuels
Policy mix
Sustainability transition
Norway

VERSION
Version 1.0

DATE
2024-12-06

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CLIENT
Norwegian Research Council

CLIENT'S REFERENCE

PROJECT NO.
102022795

NO. OF PAGES
25

SUMMARY
Despite growing attention from international and national policies, the implementation of alternative fuel infrastructure and value chains is limited in Norwegian ports. In this report, we analyse to what extent the existing international and Norwegian policies address the challenges that port actors experience in implementing alternative fuel infrastructures and value chains, particularly those based on clean hydrogen (ammonia, methanol, etc). Based on a review of IMO, EU and Norwegian policies, as well as insights from interviews and workshops done in ACES project, we conclude that the existing policies substantially address the key challenges highlighted by port actors. However, further bottlenecks remain, including lack of space in port areas, immature regulations, and limited (inter)national coordination of infrastructure networks.

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REPORT NO.	ISBN	CLASSIFICATION	CLASSIFICATION THIS PAGE
2024:01446	978-82-14-07075-0	Unrestricted	Unrestricted

Document history

VERSION	DATE	VERSION DESCRIPTION
0.1	2024-11-18	Sent to quality assurance.
1.0	2024-12-06	Final version.

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APPENDICES

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1 Introduction

Ports are central nodes in global commerce and energy flows, thus they are crucial locations for enabling the decarbonization of maritime transport, land-based transport, and industry. In particular, they serve as hubs for value chains and infrastructure for zero-emission alternative fuels, such as those based on green and blue hydrogen (e.g., methanol, ammonia, pure hydrogen, and e-fuels). Accordingly, several port organizations in Northern Europe have begun to explore how they may contribute to decarbonizing transport and industry operating in their port area. However, despite emerging interest from, e.g., clients of shipping services and shipowners, the realization of zero-carbon alternative fuel infrastructure in ports is still limited in 2024, even in a maritime decarbonization frontrunner country like Norway. This is because of technological immaturity, uncertainty of demand, and high costs.

At the same time, the production and adoption of alternative fuels has emerged as a major policy goal at both European and national levels, including in Norway. For example, in maritime transport, EU's 'Fit for 55' package sets targets for development of alternative fuel infrastructure development, while Norway aims to reduce the carbon emissions of domestic maritime transport by 50% by 2030. The overall aim of such policies is to combat climate change while also strengthening the competitiveness and innovativeness of local industries. To meet such aims, it is essential that the employed policies are effective in contributing to the realization of alternative fuel infrastructure and value chains in ports. The employed policies thus need to match with the needs of ports who play a key role in developing the required zero-emission alternative fuel infrastructure. Complexities associated with the realization full-scale hydrogen value chains (e.g., uncertainties in demand) accentuate the need for alignment between employed public policies and the remedies they may provide to solve ports' challenges in realizing zero-emission alternative fuel infrastructures.

Using Norwegian ports as a case study, this report analyses **the extent that existing international and Norwegian policies address the challenges that port actors experience in realizing zero-emission alternative fuel infrastructures and value chains**. The report seeks to provide insights regarding whether policies are aligned with the key issues in the development of such facilities, and on the remaining outstanding issues that require further attention from policymakers. We focus specially on clean hydrogen-based fuels, such as ammonia, methanol, and liquefied and compressed hydrogen, which are often considered as more scalable solutions to decarbonize shipping in comparison to, e.g., battery-electric and biofuels.

This report continues as follows: section 2 presents the methodology and research context of this report. Section 3 outlines the central policies affecting the realization of hydrogen-based value chains and infrastructure in Norwegian ports, reviewing key policies at global, European Union and domestic levels. Section 4 presents insights regarding the key challenges faced by Norwegian port actors (port authorities & owners, users, public authorities, etc.) in realizing hydrogen-based value chains and infrastructure in Norwegian ports. Section 5 assesses to what extent the existing policies are matched with the challenges that port organizations face in realizing the required infrastructures, and identifies the remaining needs that may be addressed by further policy action. Section 6 concludes the report.

2 Methodology

This report has been prepared as a part of ACES project (Accelerating Energy- and Sustainability Transitions in Ports, grant number 319068), financed by the Research Council of Norway. The project has been led by SINTEF, while research partners include the Norwegian University of Science and Technology (NTNU) and the Dutch Research Institute for Transitions (DRIFT), together with several collaboration partners from the Norwegian port sector. The conducted policy review (Section 3) was partly conducted in collaboration with INTERPORT project (Integrated Energy Systems in Ports, grant number 327024), also financed by the Research Council of Norway, and led by SINTEF.

In the policy review, through desktop research, we identified both central international policies (International Maritime Organizations (IMO) and European Union) and national policies in Norway affecting the deployment of alternative fuel infrastructure and value chains. Moreover, we used our existing knowledge of key policies, gained in prior research activities (e.g., Mäkitie et al., 2021; Mäkitie et al., forthcoming). In addition to international and national levels, also sub-national policies (e.g., at county, city and municipality levels) play a role in governing the realization of alternative fuel infrastructures and value chains, for example, through areal planning and land ownership. The review of policies at local level was however not within the scope of this report.

Recovering policy documents from publicly available sources (such as EUR-Lex and Norwegian government's websites), we recorded the central aims (what the policy seeks to achieve) and means (how the policy seeks to reach the aim) of each policy. The identified policies were seen to form a policy mix (Kivimaa & Kern, 2016; Rogge & Reichardt, 2016) that shapes the transition towards alternative fuels. The policies are summarized in Section 3.

In section 4, the insights regarding challenges in realizing hydrogen-based value chains and infrastructure are based on extensive primary material gained in the ACES project. Using 'transition management' as a transdisciplinary research approach (Hebinck et al., 2022; Kemp et al., 2007; Loorbach & Rotmans, 2010), the project established four "transition arenas" focusing on facilitating sustainability transitions in different contexts: Port of Kristiansand, Port of Bodø, and Port of Borg. In addition to these three local-level arenas, a fourth arena took a national level approach to sustainability transitions in Norwegian ports. Each transition arena utilized interviews and workshops with central stakeholders addressing the foreseen sustainability transitions in each case. Each arena sought to develop a joint understanding of the kind of transition the stakeholders thought necessary, and how such a transition would be reached. The interviews with stakeholders were the main source of information for insights presented in section 4. In addition, to bring insights from the perspective of a privately-owned port, we also used interviews with Coastal Centre Base (CCB) in Ågotnes, an offshore base in Western Norway. The research teams who conducted the interviews are summarized in Table 1.

Table 1 Transition Arenas and research teams

Transition Arenas	Research team
Port of Kristiansand	Lillian Hansen, Susanne Jørgensen, Janne Venæs

Port of Borg	Susanne Jørgensen, Lillian Hansen, Tomas Skjølsvold
Port of Bodø	Astrid Bjørgen, Susanne Jørgensen, Marianne Ryghaug, Lillian Hansen
National arena	Susanne Jørgensen, Marianne Ryghaug, Kristin Ystmark Bjerkan, Lillian Hansen, Simen Rostad Sæther, Bård Torvetjønn Haugland, Mari Wardeberg
Coastal Centre Base, Ågotsnes	Susanne Jørgensen, Marianne Ryghaug, Tomas Skjølsvold

Notably, all interviews focused on broader sustainability issues and not only alternative fuels. Hence, for the purposes of this report, out of the total available material, we only used a sub-set of individual interviews with 23 stakeholders (executed in 2022-2023) that discussed the specific challenges related to realizing alternative fuel infrastructures and value chains. The anonymized interview respondents are listed in Table 2. From each interview, the author team of this report reviewed the interview transcripts or notes to identify challenges reported by the actors. These identified challenges were noted on a spreadsheet together with descriptions and quotes. After this, the author team compared the notes to identify commonalities between the identified challenges, and after discussions, the author team agreed upon five synthesised challenges that were commonly mentioned in interviews. These challenges are reported in section 4.

Table 2 Interview respondents

Code	Informant
A1	Public agency 1
A2	Public agency 2
A3	Public agency 3
A4	Public agency 4
A5	Public agency 5
A6	Public agency 6
E1	Electricity supplier 1
F1	Alternative fuel supplier 1
F2	Alternative fuel supplier 2
I1	Interest organization 1
I2	Interest organization 2
M1	Municipality 1

Code	Informant
N1	Non-governmental organization 1
P1	Port organization 1
P2	Port organization 2
P3	Port organization 3
P4	Port organization 4
P5	Port organization 5
S1	Technology supplier 1
T1	Transport company 1
T2	Transport company 2
T3	Transport company 3
T4	Transport company 4

Based on analyses presented in sections 3 and 4, section 5 discusses the degree of alignment between public policies and the challenges reported by port actors. Here, we evaluate whether the international and national policies address the issues that port actors perceive to be key barriers in realizing alternative fuel infrastructures and value chains. Inspired by policy mix research in sustainability transitions literature (Hansen et al., 2024; Rogge & Reichardt, 2016), we do this by evaluating whether the aim and the instruments of the policy mix are aligned with the identified challenge. Ideally, the policy mix would combine policies that aim to foster the innovation (i.e., deployment of alternative fuels and value chains), and policies that aim to reduce existing solutions (i.e., phase out fossil fuels) (Kivimaa & Kern, 2016).

We determined three types of alignment between challenges and policies. First, if the existing policy mix was found to have an aim that addresses the identified challenge 1) through multiple instruments outlining

2) multiple concrete means to solve the challenge, and 3) through both international and national policy instruments, the alignment between the policy mix and the challenge was assessed to be *high*. Second, if the policy mix was found to address the challenge but have only few policy instruments with few concrete means that have been implemented, the alignment was assessed to be *intermediate*. Third, if the challenge was not addressed by the policy mix, or if instruments had not yet been implemented, the alignment was assessed to be *low*.

It should be noted that it is out of scope of our analysis to assess to what extent the identified policy mixes had been effective in solving the identified challenges. However, we expect that high alignment is indicative that policies are more likely to contribute to alleviating the given challenge over time, while low alignment is indicative that policy mix is not (yet) contributing to solve the challenge.

3 Alternative fuel policies

Building on a policy review reported in (Mäkitie et al., forthcoming), this section reviews the central public policies affecting the development and deployment of alternative maritime fuel infrastructure in Norway, particularly those related to hydrogen-based energy. Table 3 summarizes the key policies and their aims.

Table 1 Summary of the central policies

	Policy instrument	Aim of the policy
Global	IMO Strategy on Reduction of GHG emission	Reduce GHG emission in shipping by 20% by 2030, 70% by 2040 and net-zero by 2050, compared to 2008 levels.
	IGF Code	Provide industry standards for ships using low-flashpoint fuels.
	SOLAS	Specify minimum standards for the construction, equipment and operation of ships, and regulate maritime safety and marine pollution prevention.
	IGC Code	Provide international standards for safe carriage by sea in bulk of liquefied gases and other substances.
European Union	The Green Deal	Reduce GHG emissions in EU by at least 55 % by 2030, compared with 1990 levels and aim for climate neutrality by 2050
	The EU's Hydrogen Strategy	Accelerate the development of green hydrogen as a key component in the EU's energy system.
	The Alternative Fuel Infrastructure Regulation (AFIR)	Develop essential infrastructure to support the uptake of alternative fuel across all transport modes.
	The amendments of the 2003 Emission Trading System (ETS) Directive	Establish the EU's emission trading system and be a cornerstone of the EU's policy to tackle climate change by reducing GHG emissions in a

		cost-effective and economically efficient manner.
	Renewable Energy Directive (RED III)	Increase the share of renewable energy to minimum 42.5 % by 2030, with further indicative target of 2.5%.
	Hydrogen and Decarbonized Gas Market Package	Facilitate the uptake of renewable and low-carbon gases, including hydrogen, and ensuring security of supply.
	FuelEU Maritime	Reduce GHG emission in the maritime sector by promoting the use of renewable and low-carbon fuels.
	RePowerEU	Reduce the EU's reliance on Russian oil and accelerate the European green energy transition.
National	Climate Change Act	Reduce absolute carbon emission by 50% by 2030, and 90-95% by 2050, compared to 1990 levels.
	The Government's Hydrogen Strategy	Promote the development of new low-emission technologies and solutions, specifically focusing on hydrogen.
	White paper on Energy	Contribute to secure, green transitions and employment. Contribute to facilitating hydrogen production to meet domestic demand and contributing to the development of a hydrogen market in the EU.
	Government's Green Industrial Initiative	Make Norway a green industrial and energy giant based on natural resources, knowledge environments, industrial expertise, and historical advantages, and contribute to accelerating the transition.
	Pilot - E	Accelerate the development of new products and services within environmentally friendly energy technology and promote their adoption to help reduce emission nationally and internationally.

3.1 Global

On a global level, alternative fuel policies connected to the maritime sector mainly come from the International Maritime Organisation (IMO). IMO has recently set rather ambitious targets to reduce greenhouse gas (GHG) emissions from international shipping. The IMO Strategy on Reduction of GHG Emissions from Ships aims to cut total annual GHG emissions by at least 20 % by 2030 compared to 2008 levels, 70 % by 2040, and reach net-zero emissions by 2050 (IMO, 2023). This strategy signifies a significant step towards the international adoption of alternative fuels, including hydrogen and ammonia, with the aim of achieving at least a 5 % adoption rate of low-and zero-emission technologies by 2030.

Identified policies related to international regulations and guidelines of ammonia and hydrogen as marine fuels are still immature. For example, the International Code of Safety for Ships Using Gases or other Low-flashpoint Fuels (IGF Code), adopted by IMO in January 2017, sets international standards for ships using low-flashpoint liquids and gases as fuels. It focuses on the arrangement, installation, control, and monitoring of such ships to minimize risks to people, ship and the environment (Fu et al., 2023; IMO, 2024b). The IGF Code does not currently have specific provisions for hydrogen. However, it provides a framework through the Alternative Design approach to ensure compliance with IMOs Safety of Life at Sea (SOLAS) Convention. The Alternative Design approach is sometimes identified as a barrier for the adoption and uptake of hydrogen in the maritime sector, due to its comprehensive and costly documentation requirements (Mäkitie et al., forthcoming). Similarly, the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code), mandatory under SOLAS, governs the transportation of fuels such as hydrogen and ammonia by ships (IMO, 2024a). While the IGC Code already regulates ammonia transport, it may require modifications to accommodate ammonia as maritime fuel. Currently, toxic gases are prohibited under this code, and future amendments to the IGC Code will be necessary to allow ammonia as a maritime fuel, aligning with evolving safety and environmental standards (ABS, 2020). In the absence of harmonized international regulations, the Alternative Design Approach is also applied to ammonia, posing similar challenges to those of hydrogen. The IMO has expressed its commitment to addressing this gap by providing Interim Guidelines for both ammonia and hydrogen-powered vessels by the end of 2024 (DNV, 2023).

The IMO has recently begun developing conditions for the use of alternative fuels in shipping, with clear emission reduction targets and new regulations and guidelines. These initiatives signal a long-term ambition to introduce alternative fuels into international shipping. However, the direct impact of these ambitions on the development of necessary infrastructure remains to be seen.

3.2 European Union

At the European level, ambitions to decarbonize shipping and promote alternative fuels have advanced into concrete actions. Central to these initiatives are European Climate Law and European Green Deal, which commit the EU to reduce GHG emissions by at least 55 % by 2030, compared with 1990 levels, and achieve climate neutrality by 2050. An essential component of the Green Deal, the Fit for 55 package, is comprised of various initiatives and legislative revisions aimed at accelerating EU’s decarbonization efforts. Key measures within this package, particularly relevant to hydrogen-based alternative fuels, include:

- The EU’s Hydrogen Strategy
- The Alternative Fuel Infrastructure Regulation (AFIR)
- The amendments of the 2003 Emission Trading System (ETS) Directive
- Renewable Energy Directive (RED III)
- Hydrogen and Decarbonized Gas Market Package
- FuelEU Maritime

The EU Hydrogen Strategy, adopted in July 2020, presents a comprehensive framework for integrating hydrogen as a critical component of the EU's future energy system. It outlines 20 policy action points across five focus areas: investment support; stimulation of production and demand; creation of hydrogen market and infrastructure; research and innovation; and international cooperation (European Commission, 2020). A prominent initiative within this strategy is the European Clean Hydrogen Alliance, which brings together stakeholders across the hydrogen value chain to develop an investment agenda aimed at scaling hydrogen production and utilization across sectors, including in maritime transport (European Commission, 2024b).

The AFIR, which took effect in April 2024, aims to establish the infrastructure needed to support alternative fuel uptake across all transport modes within EU Member States. This regulation mandates a comprehensive refuelling and recharging network to ensure accessibility to alternative fuels, including hydrogen, throughout the EU. The AFIR sets mandatory national targets for the development of alternative fuels infrastructure, covering road vehicles, vessels and stationary aircraft. Specifically for hydrogen, the regulation requires publicly accessible hydrogen refuelling stations to be located no more than 200 km apart along the Trans-European Network (TEN-T) core and comprehensive networks, with at least one station in every urban node (European Commission, 2024a). Additionally, the Trans-European Network for Energy (TEN-E) Regulation, which came into force in June 2022, provides a policy framework for cross-border energy infrastructure, prioritizing eleven energy corridors – including hydrogen corridors – and three thematic areas: smart electricity grid development, smart gas grids, and a cross-border CO2 network (European Commission, 2024c).

A central element of the Fit for 55 package is the revised ETS Directive, which broadens the scope of the EU Emission Trading System to include hydrogen production via electrolysers, making them eligible for free allowances, aiming to incentivise production from installations that reduce GHG emissions and create a level playing field for new technologies (Nesdam, 2021). Moreover, the revised directive includes a faster reduction on the emission cap and reduce the allowance available on the market. From 2024, the ETS also applies to maritime transport emissions, covering carbon dioxide, methane and nitrous oxide emission from cargo and passenger vessels above 5,000 gross tonnage (EU, 2023a). Additionally, the Renewable Energy Directive (RED), a key component of the Fit for 55 package, aims to increase the share of renewable energy in the EU's energy mix, with the latest version (RED III) raising the 2030 target for renewables to a minimum 42.5% and reinforcing the regulatory framework for renewable energy use in transport (EU, 2023b). Complementing RED III, the Hydrogen and Decarbonized Gas Market Package, adopted in 2024, establishes a regulatory framework designed to promote hydrogen infrastructure and facilitate the adoption of renewable and low-carbon gases, including hydrogen, while ensuring security of supply (EU, 2024). Finally, The FuelEU Maritime Regulation, set to take effect in 2025, focuses specifically on the maritime sector's transition to renewable and low-carbon fuels, as well as clean energy technologies for ships. This regulation limits the annual average GHG intensity for ships over 5,000 gross tonnage calling to European ports, with a targeted reduction of up to 80% by 2050 (EU, 2023c).

In addition to the Fit for 55 package, the RePowerEU strategy, introduced in 2022, aims to reduce the EU's dependency on Russian oil while accelerating the European green energy transition. A crucial component of this strategy concerning hydrogen is the EU's goal to import 10 million tons of green hydrogen by 2030 and boost green hydrogen production by an additional 10 million tons, fostering a significant increase in the use of hydrogen as a viable alternative fuel (European Commission, 2022). The EU's involvement in the Mission Innovation Initiative further supports this ambition, with the development of "hydrogen valleys", which are integrated hydrogen networks within specific geographical areas. The Clean Hydrogen Partnership, under the RePowerEU framework, provides funding to establish these valleys, aiming to scale up hydrogen value chain (Clean Hydrogen Partnership, 2023). Moreover, the EU's launch of the Hydrogen Bank in 2022 represents a significant milestone in efforts to expand renewable hydrogen production within the EU (European Commission, 2023a). Funded through the EU's Innovation Fund, the Hydrogen Bank will allocate up to 800 million Euro over the next decade to support hydrogen production within the European Economic Area (EEA) (European Commission, 2023b).

3.3 Norway

Norway's climate action is guided by the Climate Change Act (Ministry of Climate and Environment, 2017), which establishes a goal of reducing absolute carbon emissions, compared to 1990 levels, by 50% by 2030 and 90-95% by 2050. Additionally, the Norwegian Government has set a target of reducing domestic maritime transport carbon emissions by 50 % by 2030, compared to 2005 levels (Norwegian Ministries, 2019).

To achieve these goals, the government has announced to gradually increase its national carbon fee to approximately NOK 2000 per CO_2-t by 2030 (Ministry of Climate and Environment, 2021). Furthermore, the Norwegian Act relating to Ports and Navigable Waters allows ports to impose environmental requirements on ships, allowing ports to regulate emissions also locally (Ministry of Transport, 2018). In the ferry segment, public procurement has been a crucial instrument for introducing low- and zero-emissions technologies to publicly tendered routes. Norwegian authorities frequently tender contracts to operate publicly owned ferry routes, where for some, the Norwegian Public Roads Administration (NPRA) has utilized development contracts that have strict requirements for the environmental performance of the ferry service. Such contracts have enabled industrial consortia to implement experimental technologies. Since 2015, this approach has driven the development and deployment of battery-electric ferries and to some extent hydrogen ferries, in Norway (Bach et al., 2020). Public policy measures pushing the introduction of novel low- and zero emission technologies in the coastal maritime sector have enjoyed a broad acceptance among maritime and shipping actors (Sæther & Moe, 2021). However, implementing on-shore infrastructure has occasionally proven to be challenging, as ferries often operate in remote areas with limited power grid capacity, inadequate for the high-capacity charging required by fully electric ferries. Expansion of power grids to supply, in often cases, a single electric ferry in a remote location can however be considered cost-inefficient by the regional distribution system operators managing the grids (Andersen et al., 2023). This highlights how mismatches in governing logics and institutional frameworks of actors may challenge the effective implementation of climate policies.

Regarding hydrogen policies, the Government's Hydrogen Strategy places significant importance on fostering collaboration between the maritime sector and port operations regarding the development of hydrogen infrastructure (Norwegian Ministries, 2020). The strategy views hydrogen as a business opportunity for the maritime industry in Norway. Demonstrations of maritime hydrogen solutions have been supported by the Pilot-E program, funded by Norwegian R&D financing agencies, since 2016. Pilot-E has granted demonstration support for hydrogen vessels, a hydrogen supply project and a maritime hydrogen hub (Pilot-E, 2023).

The public strategy to initiate the realization of maritime hydrogen infrastructure and value chains was further outlined in the White Paper on Energy (Ministry of Petroleum and Energy, 2021). This White Paper proposes public support for establishing five hydrogen hubs that would serve the maritime and road transport sector, as well as industry, alongside associated production facilities. In June 2022, Enova initiated this plan by awarding a total of NOK 669 million in capital expenditure support for five green hydrogen production facilities (E24, 2022). Simultaneously, funding was allocated to support 15 hydrogen and ammonia vessels, covering 40-50 % of the investment costs. However, due to e.g. high electricity price and inflation, and weak Norwegian currency, by late 2023 none of these projects had made substantial advancement. Consequently, Enova announced new support programs, offering up to 80% support of the investment costs for hydrogen production facilities for maritime use, as well as for hydrogen and ammonia powered vessels (Enova, 2023b). In June 2024, nine hydrogen vessels and six ammonia vessels were awarded grants, NOK 1,2 Billion in total (Enova, 2024a). Competition for grants for hydrogen production facilities takes place in late 2024, followed by a call for ammonia production projects.

Further implementation progress has been seen with the requirement of using hydrogen as propulsion energy as explicitly specified in two NPRA tenders for ferry routes: in Rogaland operating a short ferry route between Hjelmeland-Nesvik-Skipavik, and in Nordland operating a relatively long route in open Northern Atlantic conditions between Bodø-Røst-Værøy-Moskenes. In Rogaland, the resulting hydrogen-powered ferry, the first of its kind in the world, became operational in 2023. In Nordland, the first of the hydrogen vessels is expected to become operational in 2025. The hydrogen for this latter route will be produced in the Bodø port area by an electrolyser plant, being built simultaneously by GreenH AS. The shipping company Torghatten Nord has signed a 15 year long delivery deal with GreenH for supply to the Lofoten ferries. The aim of specifically tendering hydrogen-powered vessels was to foster zero-emission technology development beyond full-electric propulsion technology, to contribute to development of regulations surrounding maritime hydrogen solutions, to provide incentives for domestic industry to invest in the development of hydrogen technologies, and to contribute to building hydrogen infrastructure and production in Norway (Ministry of Petroleum and Energy, 2021). The Norwegian government aims to continue to include low emission requirements to forthcoming tendering of publicly governed ferry routes (Ministry of Climate and Environment, 2021).

In terms of regulations, on-shore hydrogen infrastructure is governed by the Major Accident Regulation, which mandates strict safety protocols for facilities storing five tons or more of hydrogen (Ministry of Justice and Public Security, 2016). This regulation affects, for example, required safety distances from hydrogen tanks to other facilities and built environment. Yet, generally speaking, specific regulations for using hydrogen as an energy carrier for transport are still immature and often non-existing. Developing mature regulations would simplify hydrogen infrastructure development for all stakeholders, but regulatory development is constrained by limited operational experience. Therefore, the Norwegian government has promised to ensure that the relevant regulatory authorities, such as Norwegian Maritime Authority, Directorate for Civil Protection, and Coastal Administration, have enough capacity and competences for the development of such regulations (Ministry of Petroleum and Energy, 2021). Moreover, Norwegian Maritime Authority participates actively internationally in IMO regulatory development surrounding novel energy sources for propulsion, including hydrogen and ammonia. Nationally, there is a tradition that regulatory authorities such as Norwegian Maritime Authority may collaborate with private actors in projects where novel maritime solutions, including hydrogen solutions, are being implemented to hasten the approval process.

Within the new Green Industrial Initiative from the current Norwegian Government (Ministry of Trade Industry and Fisheries, 2023), the maritime industry and hydrogen are two of nine priority areas essential to Norway's green transition. As a part of this initiative, emphasis is placed on supporting the development of new maritime fuel infrastructure and value chains. For example, key actions include the government's commitment to present a national plan to ensure the availability of climate-friendly maritime fuels. Moreover, ENOVA has announced a scheme for investment support in the production and infrastructure for hydrogen as a marine fuel and aims to support the first functional value chain for hydrogen as fuel in the maritime sector in Norway (Enova, 2024b). Additionally, the government seeks to enhance Nordic collaboration for demonstrating and testing green solutions, particularly through the establishment of green shipping corridors. Furthermore, the government has also put forward a proposal for new zero-emissions requirements for ferries and high-speed boats.

4 Challenges of implementing alternative fuel infrastructure in Norway

This section summarizes the key challenges in realizing alternative fuel infrastructure and value chains in ports, as reported by the interviewed Norwegian port actors.

4.1 Coordination challenges

Ports form a network of nodes in transport, production and energy systems. Isolated actions of an individual port are thus unlikely to lead to broad changes in such systems. This is particularly true for developing alternative fuel infrastructure, as vessels and trucks typically visit different ports, making it necessary to build networks of infrastructure to attract users. Thus, different kinds of actors, governance levels and locations are interdependent in their actions. It was therefore unsurprising that various types of *coordination challenges* were identified in our research. Coordination challenges were discussed particularly in terms of geography and technological plurality.

First, developing novel infrastructure requires not only collaboration and coordination between different regions, but also between actors in the same region (Interview M1). For example, collaboration around managing local energy needs will be necessary, especially as grid capacity may be a bottleneck in several locations when establishing, e.g., local hydrogen production (N1). There will also be a need to stay updated on the plans and ambitions of different actors in the various alternative fuel value chains and other nearby energy projects (P1), including competing developments, such as other hydrogen production projects (F1).

Moreover, improved coordination of the infrastructure build-up at the national level was mentioned. Currently, the development of alternative fuel infrastructure is seen to be fragmented and limited, focused on regional activities, rather than seeking to develop a national infrastructure network. It was therefore suggested that better coordination and the development of a holistic national plan be prioritized, including coordination regarding which solutions should be developed in which ports (A1, I1). Such a plan should adopt a long-term perspective and be based on oversights of the land and shipping transport patterns of each port to identify the opportunities and requirements for infrastructure (I1, T1). Particularly identified, more attention on the most important sea corridors is needed (P3, I1, M1). For example, Norway's Hydrogen Strategy, which does outline a goal of establishing several hydrogen hubs, was seen insufficient in filling the need for more concrete, yet holistic, planning.

Second, technological plurality was seen as a coordination challenge. Shipping is a highly heterogeneous sector consisting of various segments, ranging from small fishing vessels to giant freight transport vessels, and in Norway, different phases of alternative fuel adoption is seen (Bergek et al., 2021; Mäkitie, Steen, et al., 2022). It is therefore unsurprising that different decarbonization solutions are being explored in different types of shipping, but also within a single segment. For example, passenger vessels differ in terms of how long they can spend time refuelling at quay, which has implications for which kind of solutions are feasible for which vessels (F1). Such plurality of solutions (e.g., ammonia, methanol, LNG, electrification, pure hydrogen) poses a challenge for ports, as they do not yet know for which solutions infrastructure should be developed. Moreover, ports are unlikely to have funds or space to develop infrastructure for all kinds of alternative fuel (P2, I2, P1, T2).

> *"If we are to have a bunkering facility for hydrogen because [two ship owners] need it, we know that other ships will come that rely on ammonia, we know that others will use LNG, and we know that others have none of those and will rely on shore power. We cannot accommodate all these things."* P2

It was thus mentioned that there is a continued need to pilot and demonstrate various solutions to gain insights and experiences of their performance (A1). Such continued maturation of solutions should cover the whole value chain (A2). For example, the continued use of public procurement of ferry services was identified as a tool to pursue further demonstration of novel solutions (A3, P2). In addition, the introduction of novel technologies to vessels of public entities, such as the Navy, was mentioned as one possible means to pursue, e.g., the wider development of infrastructure (N1). In addition, more real-time information about the status and availability of infrastructure would improve practical functionality for users (A1).

4.2 Chicken and egg problem: alignment of supply and demand,

Related to the above-mentioned coordination challenges, the so-called "chicken and egg problem" between the supply and demand of alternative fuels was commonly mentioned as a challenge for the introduction of novel solutions. This has previously been identified as a typical problem especially in the case of establishing maritime hydrogen value chains (Damman et al., 2020; Mäkitie et al., 2021; Mäkitie, Hanson, et al., 2022). The systemic uncertainty regarding the location, form, and timing of supply and demand for hydrogen-based fuels hinders the investments of actors across the value chain. For example, ship owners may make investments with 20–30-year time horizons in mind, in which case an investment in a wrong fuel may result in large challenges for the company (T2). Lack of existing supply and distribution of fuels is thus a risk for shipowners (S1). From the point of view of shipowners, the infrastructure must also be available in the right time, right place and right price (P2).

At the same time, producers of hydrogen may be hindered by the uncertainty of demand for their product (F1). This applies not only to the existence of markets, but also to their extent, as larger production quantities would reduce the levelized cost, but also include a higher financial risk due to higher investment costs. Also, the available grid capacity may create additional bottlenecks within the development of alternative fuel value chains, slowing down the solutions for the chicken and egg problem.

4.3 Lack of physical space

Several ports reported lack of physical space as a challenge for establishing novel infrastructure. This was related to competing uses of port areas, proximity to inhabited areas, limitations to expanding the port area, and safety zones necessary for especially production and storage of hydrogen and ammonia.

Since ports are sites for various types of functions, they must accommodate for multiple types of uses and activities, such as storage, logistics, loading on/off ships, and parking (P3, P4, P5). Lack of space is especially problematic for ports which historically are located within populated areas, as the ports may not have adjacent physical space for further growth. Prioritization of activities, more effective land use, and novel ways to organize ports' functions (e.g., mobile rather than fixed facilities) may therefore be necessary to create space for novel infrastructure. However, in some cases such planning actions have been hindered by lack of collaboration between port users in terms of areal use (P3).

Further, the County Governor (Statsforvalteren) may intervene in land use questions, which has been the case in one of the port areas in Norway. While municipalities in Norway have responsibility for planning and land use, the County Governor is the state's representative at the county, and has the mandate to pursue the implementation of measures, goals and guidelines from the Parliament and Government, including those related to environmental protection. In land use management, the County Governor guides the correct understanding and practice of the Planning and Building Act and its associated regulations. These contribute to regional and municipal coastal zone plans, facilitating a balanced use and protection of the coastal zone, as well as land and sea use.

Safety regulations also limit the location of hydrogen and ammonia facilities inside port areas. Given that hydrogen is a potentially explosive gas and ammonia is highly toxic, safety zone regulations necessitate significant spatial requirements for such facilities (A4, A5). This is particularly a challenge in ports located adjacent to residential areas, as hydrogen and ammonia facilities may also raise local resistance due to perceived risks (P3).

Due to such issues related to physical space inside port areas, production and storage of hydrogen or ammonia may have to take place further away from quay. However, this requirement may raise fuel costs due to the need for transportation (E1, F2).

4.4 High prices and uncertainty of costs

Port actors pointed out that a significant challenge is that zero-emission hydrogen and ammonia are currently much more expensive than fossil fuel options. Indeed, Enova determined in a 2023 evaluation that the levelized cost of hydrogen in current electrolysis-based projects (green hydrogen) in Norway is projected to be aroundt NOK 60/kg in 20MW production plants. This price includes only the cost for production of hydrogen, and not, e.g., additional mark-ups and other costs of hydrogen supply (ENOVA, 2023a). Without considering carbon fees or carbon prices, this is several times more than comparable price of, e.g., marine gas oil (DNV, 2024). The price becomes even higher if hydrogen needs to be transported from production to bunkering site. The high price undermines the attractiveness of alternative fuels for users, creating uncertainty regarding market formation.

The price difference between fossil fuels can be expected to become smaller over time due to economies of scale in larger electrolyser units, as well as through increased pricing of carbon emissions. In the short to medium term, however, the high prices were seen as a barrier by several port organizations and transport companies. Further, production costs of green hydrogen-based fuels are naturally subjected to changes in, e.g., electricity price. The high electricity prices that Norwegian actors experienced in 2021-2023 were seen as a challenge for the attractiveness for different electricity-based forms of alternative fuels.

> *"Electricity prices are absolutely insane! Then the government must do something."* (P2)

It was argued by some actors that the state should have a stronger role in seeking to reduce the price of maritime hydrogen and ammonia value chain, going beyond the existing Enova and Innovation Norway support schemes (I1, A2, T4). Suggested measures included support for upscaling of value chains, such as contracts-for-difference, which would reduce risks related to operational costs (I1, T2, T4). It was further argued by others that further support programming should nevertheless be technology-neutral in nature, and not, e.g., favour ammonia over pure hydrogen (A3).

> "The state's task must be to support that the new solutions become off-the-shelf alternatives." (I1)

Meanwhile, the port organizations also face the challenge of financing the extra investment costs in new infrastructure. It was pointed by some actors that port organizations often operate with limited margins, and therefore may be limited in funds to invest in new alternative fuel infrastructure (P2). At the same time, it was also noted by others that public support for investment costs is available, and it is rather the uncertainty regarding operational costs (price of fuels) that presents a more acute barrier (I1, A6, T2).

4.5 Immature standards and regulations

Novel solutions in their early stages inevitably face challenges related to lack of standardization and regulation, as these solution are still maturing, and no dominant designs have yet emerged for both on-board and on-shore solutions. Regulations are yet lacking, as there is limited experience with the technologies. This lack of formalized guidelines creates a bottleneck for investments, as actors face the risk of investing in solutions that may not prevail in the long-term (P2). For example, hydrogen and ammonia bunkering are still immature in terms standardization and multiple types of bunkering solutions are being explored (F1, P2, A1). Thus, as standards are yet lacking, various ship owners set different kinds of specifications for their wishes for hydrogen bunkering solutions (F1). Ammonia is even more immature as an alternative fuel. Here, standards and regulations are lacking, creating a challenge for early-adoptors to develop innovation solutions (E1). Broadly speaking, competences and experiences related to the use of hydrogen and ammonia in maritime use is currentl insufficient (P2, Normann et al., 2023).

5 Alignment between policies and the needs of port organizations

In this section we evaluate the alignment between the identified policies (section 3) and challenges reported by the Norwegian port actors (section 4). Table 4 summarizes this evaluation.

Table 4: Alignment between identified challenges and the existing policy mix

Challenges	Relevant policies	Features	Alignment
Coordination challenges	• IMO regulations • EU Hydrogen Strategy • European Clean Hydrogen Alliance • Clean Hydrogen Partnership • EU AFIR • TEN-E • TEN-T • PILOT-E • ENOVA support schemes • Norway's public tendering	• Development of IMO regulations create cross-national collaboration • EU policies facilitating collaboration across the hydrogen value chain • EU AFIR and TEN-E foster cross-regional networks of infrastructure • National funding schemes and public procurement fostering collaboration and technological experimentation • No Norwegian alternative fuel infrastructure plan	High
Chicken and egg problem	• EU Hydrogen Strategy • EU AFIR • TEN-E • Hydrogen and decarbonized gas market package • FuelEU maritime regulation • Clean hydrogen partnership • Norway's Climate Change Act • Norway's public tendering • Norway's Hydrogen Strategy • Pilot-E and ENOVA • Norway's Green Industrial Initiative	• Directionality through emission reduction objectives • EU policy's focus on stimulation of both production and demand • Various EU policies supporting hydrogen infrastructure • Funding for hydrogen valleys and hubs • National commitment to infrastructure development • Few instruments coupling production and demand directly	High
Lack of physical space	• EU AFIR • Norway's Hydrogen Strategy • Planning and building Act	• AFIR pursuing mandatory infrastructure building • Shared infrastructure between sectors is promoted • Limited attention in national and international policies	Low

High prices and uncertainty of costs	• EU Hydrogen Strategy • EU Hydrogen Bank • EU ETS reform • RED, RePowerEU • Hydrogen and decarbonized gas market package • Norwegian carbon fee • ENOVA support schemes	• EU support for hydrogen investments • EU ETS and Norway's carbon fee making alternative fuels more competitive • RED and other policies accelerating renewables • ENOVA investment support • No OPEX support (e.g., contracts-for-difference)	High
Immature standards and regulations	• IGF code • SOLAS • IGC code • Norwegian Government's White Paper on Energy (Energi til arbeid)	• Regulatory development at IMO, but specific regulations still lacking • Commitment of national government to regulatory development, but still on-going • Lack of attention to bunkering	Intermediate

In terms of geographical and technological ***coordination challenges,*** the identified issues are addressed in the policy mix in several ways. The development of IMO regulations promotes an international understanding of the possibilities of novel technologies. Additional, various EU policies aim to foster the emergence of networks and collaborations between actors across regions, sectors and stakeholders. Norway's Hydrogen Strategy also emphasises this objective. On a more practical level, the various Norwegian project funding instruments for innovative technologies, namely ENOVA and Pilot-E funding, and public tendering of ferry routes, have played a critical role in supporting experimentation of different technologies and vessel types, thereby reducing uncertainty caused by technological plurality. Moreover, these mechanisms have enabled actors to create collaborations through project consortia that can develop further innovation. Meanwhile, EU initiatives such as TEN-T, TEN-E and AFIR seek to create European networks and corridors of infrastructure and transport routes operating on alternative fuels. In Norway, ENOVA-funded hydrogen hubs have contributed to initiating a network of infrastructure. However, the resulting network is fragmented and lacks integration with major transport hubs, often focusing on individual vessels and niche markets. Consequently, there appears to be no comprehensive strategy or holistic plan to coordinate the construction of alternative infrastructure in Norway. Nevertheless, due to otherwise strong attention from policy to this challenge, **we assess the alignment between the policy mix and the coordination challenge to be high.**

The ***alignment of supply and demand (chicken-and-egg problem)*** is addressed in several of the existing policies. At the general level, the relatively ambitious climate targets at IMO, EU and national levels set a clear direction towards introduction for alternative fuels. While important for communicating the directionality of public policy, such broad targets alone are insufficient to solve the challenges for the introduction of novel solutions . Building of infrastructure is considered a key first step part of solving the chicken and problem (Leibowicz, 2018; Mäkitie et al., 2021), and above-mentioned EU (AFIR, TEN-E) and national policies (ENOVA, etc.) are taking steps to this direction. Meanwhile, the policies aiming at the formation of hydrogen valleys and hubs take a full value chain perspective, stimulating interaction between actors across the supply and demand chains. Other policies discuss the challenges associated with the chicken and egg problem but are vague in means to implement them. For example, the Norwegian Hydrogen Strategy promotes the development of hydrogen hubs and encourage stakeholder collaboration but lacks specific mechanisms to ensure demand from e.g. the shipping sector. Similarly, RePowerEU policy aims to increase hydrogen production but does not ensure that this aligns with specific hydrogen demands, leaving possible gaps in matching supply and market needs. Despite of these shortcomings, the policy mix is clearly recognizing the challenge of overcoming these challenges. **We thus assess the alignment as high.**

The ***lack of physical space*** for alternative fuel infrastructure and value chains in ports emerged as an important practical challenge. Only a few policies at international and national level are seen to address this issue. Norway's Hydrogen Strategy highlights the benefits of considering industrial synergies and co-locating stakeholders to take advantage of the land-area required for hydrogen production, storage and refuelling. Meanwhile, AFIR seeks to create mandatory corridors of infrastructure, setting a priority to infrastructure building. However, these policies do not offer specific guidelines and measures for managing the issue of physical space. **We thus consider the alignment as low.** This is not very surprising, as land use management are typically within the jurisdiction of city authorities which were excluded from our analysis. In Norway, the County Governor may also seek to stimulate alignment between national policies and local land use.

Regarding ***high prices and uncertainty of cost*****,** multiple policies have provided financial support mechanisms for investment costs. The EU has offered financing for hydrogen projects through various instruments, while Norway's mechanism through, e.g., ENOVA has offered public financing for hydrogen projects with up to 80% of investment costs. Meanwhile, policies such as the EU ETS reform as well as Norway's carbon fee put pressure on continued fossil fuel use. Policies such as RePowerEU and RED aim to increase renewable energy and hydrogen production, thus supporting availability, which can lead to reduced costs over time. However, despite investment support, several Norwegian actors have called for further policies to reduce uncertainty regarding the price of fuels, such as contract-for-difference. Nevertheless, particularly due to the extensive ENOVA support, carbon fees, EU ETS, and other instruments, **we consider the alignment as high**.

In terms of the challenge of ***immature standards and regulations***, IMO is actively working on establishing standards and keeping international legislation updated. The same applies to Norwegian authorities. However, IMO is also under critique for its lack of capacity to regulate emerging technologies and for not developing a consistent policy mix for decarbonization (Bach & Hansen, 2023). Meanwhile, the Norwegian government has committed itself to increasing and developing the capacity and capabilities of its agencies to regulate novel technologies. Despite these efforts, specific regulations governing various alternative fuels and infrastructure are still lacking. There is a need for faster development and implementation of regulations and guidelines, e.g., for hydrogen and ammonia bunkering, which can contribute to providing clarity for ports and the shipping sector with which to make investment decisions into technologies and infrastructure. Seen overall, however, regulatory development is relatively slow, especially when safety is of importance, as regulations must be based on sound experience regarding the technologies and infrastructure. **We thus assess the alignment as intermediate**.

In summary, several challenges – including high cost of hydrogen infrastructure and the need for regional and national coordination – are to a large extent addressed by existing international and national policies. However, such policies tend to focus on broad environmental goals and financing mechanisms, such as emission reductions and alternative fuel promotion. As a result, they do not always address the practical barriers faced by ports, such as lack of physical space.

6 Concluding discussion

Ports play an important role in decarbonizing maritime and land-based transport and industry serving as hubs and facilitators of alternative fuel infrastructure and value chains. Over the last decade, the international policy landscape has increasingly supported the implementation of alternative fuels, particularly hydrogen-based fuels such as methanol and ammonia, but also electrification and biofuels. However, infrastructure development for alternative fuels remains limited in Norway and the rest of Europe. Thus, this study aimed to investigate to what extent the current international and Norwegian policies are aligned with the challenges that Norwegian port actors face in implementation of zero-emission alternative fuel infrastructures.

The analysis reveals that there is notable alignment between the existing international and national policies and the perceived challenges. This means that policymakers and port actors have a similar understanding of the central topics and points of emphasis of what is needed to advance the transitions towards alternative fuels. In particular, policies are in place to address technological and geographical coordination challenges, the chicken and egg problem of supply and demand, and high prices and uncertainty in costs. Generally speaking, the policy mix is relatively coherent and consistent in terms of aims and policy instruments (Rogge & Reichardt, 2016). Particular to high prices and uncertainty of costs, the policy mix even has features of both supporting novel technologies (e.g., notable investment support schemes) and reducing the use of old technologies (e.g., carbon price and fees) (Kivimaa & Kern, 2016). IMO and national authorities have recognized the need to mature rules and regulations, but the regulatory work is still unfinished. As the expected to the general alignment, challenges related to local land use, such as lack of physical space in (especially urban) port areas, are typically topics that are outside of the jurisdiction of national and international authorities.

This then raises the question of if the alignment is relatively high, why is the development of alternative fuel infrastructure and value chains still slow? Even though policies address the challenges at a general level, the policy instruments and means may still be considered insufficient by the actors. For example, several actors have requested contracts-for-difference, where a price is settled at a given time and the government cover the difference between that and actual price, to reduce the uncertainty of operational costs when adopting alternative fuels, but the national authorities in Norway have chosen not to introduce such a policy. The calls for contracts-for-difference reflect the high uncertainties related to alternative fuels, not only in terms of technological and regulatory immaturity, but also in terms of recent high electricity prices and interest rates Instead, the policy instruments have been limited to (relatively generous) investment support, notably the recent ENOVA support of 80% of investment costs.. Moreover, while policies have addressed broad goals and offered initial incentives, they partly lack more targeted mechanisms required to address port-specific needs for establishing alternative fuel infrastructure and value chains. For example, although there has been significant support for individual hydrogen hubs in Norway, there remains a lack of national planning to coordinate infrastructure development efforts.

While policies are key in implementing alternative fuels, their infrastructure and value chains, it should be noted that due to, e.g., high variation of technologies and user segments, and value chain interdependencies, fundamental transitions towards new solutions in sectors such as shipping and land transport are arduous and slow (Bergek et al., 2023), typically taking place over several decades (Bento & Wilson, 2016). Moreover, leadership from pioneering ship owners and energy suppliers, customer demand for zero-carbon transport, and further technological development and experimentation are necessary (Mäkitie, Steen, et al., 2022; Poulsen et al., 2016; Poulsen et al., 2018).

In conclusion, we propose the following recommendations based on our analysis.

- Continued policy leadership is needed due to high uncertainties in market formation in alternative fuels and infrastructure. The implementation of alternative fuel infrastructure and value chains in ports faces multiple and complex challenges. Further continuation and development of policies to address such challenges are necessary.
- More holistic planning and coordination of infrastructure construction is needed. While especially national policies have until now focused on local and individual projects, the next stage could seek to establish national and international networks of alternative fuel infrastructure and green shipping corridors.
- Public procurement and other demand-side policies to incentivize the implementation of alternative fuels have been powerful in creating momentum for innovation. Clear and predictable customer demand ensures higher investment security for both producers and users of alternative fuels.
- International and national policymakers, within the jurisdiction of regional and local authorities, should not overlook the central bottleneck of lack of space within port areas. For example, investments in mobile infrastructure and bunkering can be supported, and incentives for space optimization and prioritization can be explored, while regulatory demands for infrastructure implementation in key transport corridors may be set.
- Further regulatory development at IMO and national levels is paramount for removing obstacles for investments in alternative fuels and infrastructure. Sufficient capacity and capabilities in regulatory development are needed to accelerate this process.

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