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A green maritime shift: Lessons from the electrification of ferries in Norway

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ABSTRACT

Norway is at the forefront of a transition toward cleaner solutions in the maritime sector. In 2015, the first fully electric ferry, the MF Ampere, started operating in Western Norway. Since then, 60 electric or hybrid-electric ferries are in operation or scheduled to be by the end of 2021. With a few exceptions the literature on energy transitions sees transitions as disjointed and slow. Through this case study—based on 13 semi-structured interviews, two focus groups, as well as seminars, conferences and workshops with industry experts, public sector stakeholders, and project managers—we show how the Norwegian ferry case is an example showing that, under the right circumstances, energy transitions can however be politically accelerated, even in what is widely deemed a hard-to-decarbonize sector. This is one of the first attempts at analyzing the politics of accelerated transitions within the maritime sector. It is also one of few studies of the electrification of ferries, and at the end of which we suggest a set of success criteria for accelerated transitions. We propose four main explanatory factors: First, what we label the Norwegian ferry innovation system was instrumental in providing an environment conducive to electrification. Second, the Norwegian state acted entrepreneurially, by moving beyond merely being a de-risker through playing an active role in market creation and transformation through public agencies and support schemes. Third and fourth, we argue that the relative lack of strong opposing vested interests combined with an oil shock to create favorable conditions for structural change.

1. Introduction

Energy transitions are slow. Smil [1] states that they take decades to materialize, and that the current renewable energy transition will be no different. Human-induced climate change makes this an uncomfortable statement. The need to accelerate the current transition is obvious. Indeed, Sovacool [2] argues that under certain conditions, some regional and national transitions have been quite fast. The politics of accelerating transitions is however poorly understood and sorely understudied (e.g. [3,4]).

In this article, we study the electrification of ferries in Norway as a case of accelerated transitions. Norway is at the forefront of a maritime energy transition (e.g. [5,6]), with the first fully electric ferry, MF Ampere, commencing operations in 2015 [7]. As of mid-2021, 60 of Norway's around 200 ferries in operation are now either electric or hybrid-electric. Norway recently specified that by 2023 ferry tenders will only be awarded to low- or zero-carbon emission ferries [8]. Energy transition studies often focus on the power sector. By comparison, with the exception of electric vehicles, the transportation sector is understudied, despite being significantly larger in terms of energy consumption (e.g. [9]).[1] Within transportation, the focus has primarily been on road transport, with far less attention given to maritime emissions. However, globally the maritime sector accounts for 10% of transportation emissions [12] and 2.9% of total emissions [13]. According to the International Maritime Organization (IMO), which is the UN body tasked with regulating and monitoring emissions from international shipping, greenhouse gas (GHG) emissions from shipping are expected to increase from 90% of 2008 emissions in 2018 to 90–130% of 2008 emissions by 2050 [13]. Instead, they need to fall by 50% [14], underlining the massive challenge ahead. Shipping is also considered a hard-to-decarbonize sector, as long-term decarbonization options such as ammonia and liquid hydrogen are not yet commercialized at a scale needed for massive utilization [15]. Even in smaller-size shipping segments, such as ferries, battery developments have only recently materialized as a probable path forward.

Granted, while the majority of the global shipping sector is commercial, the domestic ferry sector is by and large organized with competitive tenders and operated as a public service. We still argue that

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[1] The power sector accounts for 17% of total final energy consumption, the transportation sector 32% [10,11].

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important lessons can be learnt and that this case study shows that energy transitions can indeed be accelerated, even in hard-to-decarbonize sectors. We argue that this requires considerable coordination efforts between the state and the market actors and that it is inconceivable that market mechanisms alone would have produced a similar result. More specifically, we show that it was possible because of a mix of features: First, Norway has a ferry innovation system characterized by a culture of close collaboration, mutual trust, and information-sharing. This made it possible to overcome potential initial resistance to electrification and for the maritime sector to pull in one direction.

Second, crucial to success was the state actively intervening to remove first-mover risks and costs associated with new and unproven technology. The two public entities responsible for ferry tenders, the Norwegian Public Road Administration (NPRA) and the Norwegian counties, deliberately sought to bring actors from different fields together to create credible solutions. The involvement of the state was also a case of identifying co-benefits. Stakeholders who engage in energy transitions do it for many reasons, with mitigation of climate change often lower on the preference list than, for instance, energy security or business opportunities [16,17]. For the state, involvement was made attractive by electrification being neither climate policy nor industrial policy, but a combination of the two, whereas for the industrial actors it represented a business opportunity. Thus, while the emphasis on reducing emissions is sincere, what made the ferry sector an alluring case for decarbonization was the potential for exploiting existing competitive advantages and creating an industrial cluster within battery production and green maritime shipping—both potential growth sectors. Thus, the state went further than simply de-risking. Instead, in the words of Mazzucato ([18] p.9), the state acted entrepreneurially, serving as a key partner of the private sector.

Third, also important was the lack of resistance from vested interests. The maritime sector constitutes a politically influential potential brake on electrification. Instead it was possible to create win–win solutions. Thus, Schumpeterian creative destruction [19] proved easy because the parties were able to focus on the creation part, without having to worry about the destruction of jobs and industries. In addition, fourth, transition was accelerated by a shock, namely the 2014 oil price crash, which inflicted empty order books on a maritime sector overly dependent on orders from the petroleum sector, providing an incentive to find new markets. Electric ferries became a welcome potential opportunity.

While there are undoubtedly case-specific factors making Norway a more obvious choice for the decarbonization of shipping than most nations, the policy implications are potentially great. There are lessons that can be transferred from the Norwegian maritime sector to the maritime sectors of other countries regarding transfers of technologies, institutional frameworks, and interactions between industry and state. This is also an example of the energy transition pursuits of a small state meaningfully contributing to accelerating energy transitions on a larger scale.

The article contributes in several ways. First, it contributes to the literature on accelerated energy transitions. The Norwegian case, exemplifying an accelerated transition within a hard-to-decarbonize sector, is a crucial case for theory development on accelerated energy transitions. Second, this is one of very few studies on the electrification of ferries, and one of the first attempts at analyzing the politics of the maritime energy transition. Third, it provides success criteria for accelerated energy transitions.

2. Literature and theory

Energy transitions can be defined as fundamental, long-term, structural changes in the energy system [10], affecting all its parts. Thus, previous energy transitions have typically led both to transportation revolutions and revolutions in the fuel source for energy production (e.g. [20,21]). Smil [1] however asserts that what they all have in common is their long duration. Energy transitions take generations, some even go beyond a century [22]. All predictions about a rapid renewable energy transition have failed because their promoters thought the present transition, unlike previous ones, could be rapidly accelerated ([1] p.136). The literature on the political dynamics of energy transitions suggests that transitions are difficult and protracted— "messy, conflictual and highly disjointed" ([23] p.323).

Against the view of transitions as slow and tenuous, Schmitz [17,24] stresses that there are indeed examples of rapid transformations, where green policies have been politically fast-tracked. Sovacool [2] provides 10 short case studies, suggesting that under certain circumstances transitions can be rapid, namely when there are "synergistic advances in multiple domains at once" ([2] p.211), domains such as energy, materials science, computing, etc. Both however stress that there is no magic formula and no overarching theory. Transitions are complex, context-specific, and dependent on timing, and states have different institutions, political systems, resource abundances and energy-security situations. The focus on political accelerations however suggests a focus on the actors instrumental in accelerating change. Here, the literature is scarcer. Already in 2012 Markard et al. [25] argued that how to promote and govern sustainability transitions would become a prominent topic. Yet, at the end of the decade Stokes and Breetz [4] lamented that while many studies examine technical, economic and policy drivers, little attention is paid to the political dynamics of transitions. True, there are examples of articles looking at political dynamics. Kotilainen et al. [26] focus on the combating of multiple lock-ins in their explanation of accelerated transport transitions in the Nordic countries. However, Hess [27] highlights that, as a rule, research on the policy failures behind slow energy transitions has been context-specific rather than looking for general conditions, whereas Roberts et al. ([3] p.305) emphasizes that while the renewable transition is actively pushed by policymakers, "the crucial issue of the politics surrounding their deliberate acceleration, remains under-examined".

The literature on the deliberate acceleration of the maritime sector is still in its infancy, and much existing work focuses on the technical. Gagatsi et al. [28] analyzes the potential for E-ferries in Europe, Reddy et al. [29] discusses the technologies of zero-emission ferries (using Norway as a case), whereas Ančić et al. [30] analyzes power options for ro-ro passenger ships. Of scholarly work with a social science content, the number of recent publications looking at maritime sustainability transitions using Norway as a case underline our claim of Norway being at the forefront of a maritime transition. Bergek et al. [9] argues that maritime transport has been neglected within sustainability transitions research. Several articles focus on procurements. Bergek et al. [9] and Sjøtun [7] highlight the role of the ferry Ampere in contributing to green public procurements in Norway, and Bjerkan et al. [31] argues that public procurement was used by policymakers for market creation and transformation, pushing suppliers to develop and offer greener solutions for the public sector. Berntsen et al. [32] focuses on human judgment and dialogue in ferry procurement processes. Sjøtun and Njøs [33] discusses Norwegian cluster policy and the green reorientation of clusters, the maritime sector being one of these. Hessevik [34] analyzes how Norwegian maritime clusters have used networking and lobbying to influence a green shipping transformation. Bjerkan and Seter [35] and Bjerkan et al. [36] both focus on technological challenges and their political solutions with respect to port infrastructures (providing power from land to vessels, on-board battery packs and the regulation of emission limits for docking in ports, etc.). Yet, despite this rapid and welcome growth in maritime transition literature, this article is one of very few to focus directly on the deliberate acceleration of such transitions. In our story, we very much emphasize that the Norwegian case should be read as a mix of country-specificities, contingencies, and general theoretical drivers for change. Thus, what we seek to contribute is both an explanation for Norway per se, and a more general framework for accelerated transitions.

We suggest four theoretical avenues that might help us understand how it may be possible to accelerate decarbonization processes.

First, we turn to the national system of innovation literature. Introduced by Freeman [37],[2] there is no single definition, but innovation and learning, and the diffusion of new technologies through webs of interactions between public and private sector actors, are central. A well-functioning innovation system consists of organizations, institutions, and linkages that generate, diffuse, and apply scientific and technological knowledge. Most definitions share a focus on interactivity—actors communicate, co-operate, and establish relationships that lead to the creation of knowledge and the exploitation of existing knowledge, domestically and abroad ([38] p.5). Patterns of interaction are stable over time, with distinct national features [39]. The main components are organizations (primarily firms) and institutions, the latter thought of as habits, norms, routines, rules, and laws, i.e., the rules of the game. Edquist ([40] p.196) characterizes the patterns of interaction as ones of either competition, transaction, or networking. Networking involves knowledge transfer through collaboration, cooperation, and long-term network arrangements. There is ample empirical support that networking, i.e., the interactive learning among organizations, has been crucial for innovation (e.g. [41]). Thus, we can expect that structural change is more easily pursued in systems characterized by networking, cooperation, and openness, the different industrial actors sharing knowledge when possible and acting together, rather than constantly engaging in cut-throat competition.

Second, Mazzucato [18] suggests a need to go beyond innovation systems. She emphasizes how the notion of the state as merely a facilitator belongs to the past. The onus on actively bringing actors together—state, industry, finance, research—can also be found in the systems of innovation literature (e.g. [37,42]), the historical literature (e.g. [43,44]), as well as scholarship on, for instance, energy security (e.g. [45]). Mazzucato ([18] p.74) stresses that the state must move beyond the clichés of either merely supplying research funding or actively picking winners. Instead, the state is a key partner of the private sector. It coordinates intra-industrial exchange, inter-sectoral linkages, intercompany linkages and the private–public space. It inserts low-carbon requirements in public procurements, and it "takes on risks, shaping and creating new markets" ([18] p.9). Prontera [45], in his description of the catalytic state, mirrors this. The catalytic state does not resolve the tensions between market and state, but combines them, forging coalitions between public and private actors. The state is not passive. In fact, the most successful states are those that have "collaborative power", i.e. the ability to creative cooperative agreements and consortia for action [46]. This is important in a field like the decarbonization of ferries, where easy market-based solutions are hard to identify. Thus, the entrepreneurial state goes further than just de-risking the private sector, "but envisions risk space and operates boldly and effectively within it to make things happen" ([18] p.6).

Third, historically, political resistance has been widespread (e.g. [43,47]), as transitions create both winners and losers, the losers typically being old energy incumbents with ample time to organize, influence regulations and institutions, lobby politicians, etc. Thus, transitions routinely meet with vested interest resistance. Mildenberger [48] suggests that climate politics is particularly difficult, as the dispersion of carbon polluters across the political spectrum means that labor actors and business actors have captured policymaking on the left and the right, leading to incremental change at best. For politicians, going against major vested interests comes at a cost. Decisions with large redistributive consequences are politically risky. Instead, the safe bet is to back established carbon interests and eschew major structural change, pushing energy transition into the distant future (e.g. [49,50]).

This derives from Joseph Schumpeter's [19] emphasis on creative destruction and structural change—electric ferries constituting a significant maritime structural change and a potential process of creation. However, often structural change is delayed or blocked by actors with a stake in the perpetuation of the existing system. Kivimaa and Kern [51] points out that energy transitions consist of both creation and destruction. This means policies aimed both at creating the new and destabilizing the old. The creation part is comparatively easy, i.e. niche support (e.g. [52]). But without destabilizing policies to phase out the old, which is always politically more difficult, transition is unlikely.

A potential answer comes from Kelsey [53], who divides industrial actors into winners, losers, convertibles, and management. Winners and losers are the actors that gain from change or indisputably lose. (The management category is not particularly relevant here.) The interesting category – directly relevant to the ferry case – is convertibles: "[c]onvertible industries are industries that make polluting products but do have the capability to switch to non-polluting products" ([53] p.620). First, we cannot take for granted that the ferry sector would automatically electrify, regardless of the energy alternatives. Second, this is an attempt at accelerating change, in a situation where it is not obvious that electrification represents any short-term economic gain over existing solutions. (It does for climate reasons but that is a different matter). There is also economic risk associated with several technological and infrastructural solutions necessary for electric ferries to be viable. This all suggests a sector where vested interests might resist change rather than embrace creative destruction. At the same time, in the ferry sector, the key requirement is not a specific source of propulsion but that the ferries run reliably, efficiently and turn a profit, conceivably making them convertibles rather than losers. If so, this is a sector where creation might happen without destruction being necessary.

Many argue that the world's energy situation is best described as one of carbon lock-in (e.g. [54]). Thus, a fourth and final suggestion comes from Aklin and Urpelainen [55], who theorizes that carbon lock-in is so prevalent that no change will happen unless there is a prior exogenous shock that re-politicizes the field. Change is not automatic, but shocks bring a potential for change by creating a window of opportunity for policymakers to regain autonomy over vested interests and stake out a new course. History has given us many examples of shocks that have led to the acceleration of change, e.g. the 1970 s' oil crises, Chernobyl, or the 2011 tsunami in Fukushima (e.g. [2,56,57]). For a major petroleum exporter with a huge offshore industry like Norway, the 2014 oil price drop was a serious shock.[3]

3. Methodology

Data was gathered from 13 semi-structured interviews, two focus group interviews,[4] and high-profile workshops and conferences. Additionally, document analysis was conducted in parallel alongside the progression of the case study. Interview guides can be found in Appendix A3. Our respondents constitute a wide range of actors and stakeholders, including county project managers and representatives from governmental agencies and the private sector. Some interviews were conducted between 2018 and 2020 as part of data collection for the Horizon2020 project ECHOES[5], including a best-practice case study of the implementation and decision-making process of the electrification of a Norwegian ferry crossing presented to the European Commission [59]. Additional interviews were carried out in 2020 specifically for this paper. The respondents were chosen for their expertise and viewpoints, with an aim to cover relevant aspects of the political and technological aspects of the electrification of Norwegian ferries. The respondents'

[2] Freeman's definition ([37] p.1): The network of institutions in the public and private sectors whose activities and interactions initiate, import and diffuse new technologies.

[3] At the most, the oil price fell from $115/barrel (June 2014) to 26$ (January 2016) [58].

[4] The topic of some interviews and focus groups was not exclusively on electric ferries, but ferries were either explicitly discussed, or related issues were discussed.

[5] Webpage: https://echoes-project.eu/

names and identifiable positions are anonymized. Because of sensitivity issues surrounding contracts, support schemes, and opinions provided in the interview setting, we have not used direct citations. One should be cautious about drawing strong conclusions from single interviews, thus unless specified, the data we present represents the views of a clear majority of the respondents. For a list of respondents and their approximate titles and positions (e.g. project manager, county), see Appendix A1. Stakeholder interviews provided valuable insights that are hard to obtain by assessing official documents and statements. The interviews were first transcribed and loosely coded based on our preliminarily understanding of the case and theoretical assumptions (e.g. decision-making affected by changes in policy/procurement practices, barriers for electrification, collaboration among actors, alternatives to electrification). The interview data thus uncover and highlight aspects of this transition that are not well-known and that provide relevant insights as well as revealing success criteria and pitfalls that others can learn from. The full case-material was then re-analyzed and iteratively refined for the final analysis presented in the article.

We also attended six conferences and workshops: in 2018 the Zero Conference (annual climate conference in Oslo, Norway) and a workshop on the electrification of the maritime sector in Bergen, hosted by Zero; in 2019, Ocean Week in Trondheim, Norway, a workshop on green growth in Trøndelag county, and the Zero Conference; finally, in 2020 the Enova Conference in Trondheim. The attendance and presented materials obtained provided us with cross-referencing data, allowing us to adjust, support, or question statements from interviews. The complete list of conferences and seminars is provided in Appendix A2.

Additionally, official documents, white papers, sector strategies, national and regional sector strategies, and media statements from stakeholders are part of the case material, acting as supplementary information to our overall understanding. Central policy documents and reports were the Green Maritime Action plan (2019) [60], Parliamentary Proposition 78S. (2015–2016) [61], and the consequent Report to the Storting (2015–2016) [62], Menon Economics report on Green Maritime Export Strategies (2021) [6], and Report to the Storting: Greener and smarter - Tomorrow's maritime industry (2020–2021) [8]. Additionally, we relied on media coverage in both national, regional, and local media as well as articles published in technical magazines like Teknisk Ukeblad [63], and climate- and energy focused publishers like Energi og Klima [64]. We accessed these documents and reports through web searches, which in some cases contributed to the preparations for the interviews and as cross-referencing interview data, and in some cases to statements made or referred to at conferences and workshops. In sum, this approach enhanced our understanding of the transition dynamics from a broad range of stakeholder perspectives.

4. Norwegian climate policy and the state of the Norwegian ferry sector

Norway recently increased its GHG emissions reduction target from 40% in 2030 to 50–55%, with an ambition of 90–95% reduction by 2050 (compared with 1990 levels), in accordance with the Paris Agreement and improved EU ambitions [65]. Substantial reductions must be made in areas that are not covered by the EU ETS, like the road and maritime sectors. Additionally, the Norwegian counties have ambitious climate targets as well as a national and partly regional ambition to drive new and greener growth in the maritime sector [5]. The responsibility for ferries is split between the counties and the NPRA.[6] This creates interesting possibilities related to procurement practices and the economic opportunity space in the ferry tenders, as for instance with the tender for the first electric ferry, Ampere, and is one of the few segments of the county economy where it is possible to cut emissions[7] (e.g. [7]). In 2017, Norway had 203 ferries, with an average age of 26 years, accounting for 12.7% of total domestic shipping emissions and 1.4% of Norwegian CO_2 emissions, as well as being a considerable source of local air pollution in ports [60]. With an old and polluting fleet, an upcoming replacement phase created a window of opportunity for the electrification of ferries, thus reducing the average age of the fleet while significantly cutting emissions and air pollution.

In 2015, after considerable political debate and involvement from environmental NGOs, maritime clusters and industry lobby groups, the Norwegian Parliament passed a ruling that all new ferry tenders must require low-emission technologies if possible/feasible [62]. The push was partly driven by a broad coalition across party lines and lobby organizations as the effect of the oil price drop in 2014 heavily affecting the petroleum sector and Norwegian shipyards, both industries with considerable political influence [61]. The government's goal was to electrify or provide low- and zero emission solutions to all ferries by 2025, which has since been pushed forward to 2023 [8].

As of early 2021, Norway has 34 ferry crossings that are fully electric or hybrid-electric with a considerable electrification rate (and one hydrogen ferry), and 57 crossings scheduled for electrification.[8] Annually a standard electric ferry saves over 2,500 tons of CO_2 and 800,000 L of diesel [67]. The most trafficked ferry crossing in Norway, Horten-Moss, which transports 1.8 million vehicles and 3.7 million passengers annually across the Oslo fjord, is scheduled to be fully electric by summer 2022.[9] For most new tenders, the winning contract has been awarded to ferry designs with battery-electric systems on-board with back-up diesel or gas-electrical propulsion systems that use second generation HVO biodiesel or biogas providing redundancy and securing regularity of operations. There are also examples of tenders for retrofits of existing ferries to battery-electric systems. Apart from contractual emission limits and reductions put in tenders, which have been crucial for the development toward electric ferries (e.g. [5,68], electricity is cheaper than (bio)diesel and LNG in Norway. Thus, there are incentives to maximize the rate of electrification.

The NPRA has contracted with ferry operator Norled to provide the world's first hydrogen-electric ferry, scheduled to start operating in Rogaland County from fall 2021.[10] The Norwegian government also wants to tender a hydrogen solution for Vestfjorden, a three-hour ferry crossing from Bodø to Lofoten, by 2024 [70]. Fig. 1 shows a county-by-county overview of the number of operational ferry crossings that have been electrified and are scheduled to be electrified (including hydrogen ferries) in each specific year. For details, see Appendix B1.

5. The electrification of Norwegian ferries

Norway's swift transition toward electric ferries is an example of an accelerated transition within a hard-to-decarbonize sector. We suggest that four main explanatory factors were crucial for electrification developments in the Norwegian ferry sector. First, what we label the "Norwegian ferry innovation system" played a major role in creating the conditions and environment where electrification of ferries could happen. Second, the Norwegian state acted entrepreneurially, moving beyond merely being a de-risker and playing an active and crucial role as

[6] The NPRA is responsible for 16 ferry crossings and the counties 102 (including very short crossings). Additionally, five crossings will be replaced by bridges/tunnels.

[7] For many Norwegian counties a considerable amount of emissions under their responsibility comes from public transport like buses, ferries and high-speed ferries.

[8] For a graphical overview of electrification of ferry crossings, see https://energiogklima.no/nyhet/gronn-skipsfart/gronnskipsfart-naermere-60-elektriske-bilferger-innen-2021/ [66].

[9] One newbuilt electric ferry started operating in March 2021, two are to be electrified by 2022.

[10] MF Hydra is the first ferry in the world to use a liquefied hydrogen fuel cell [69].

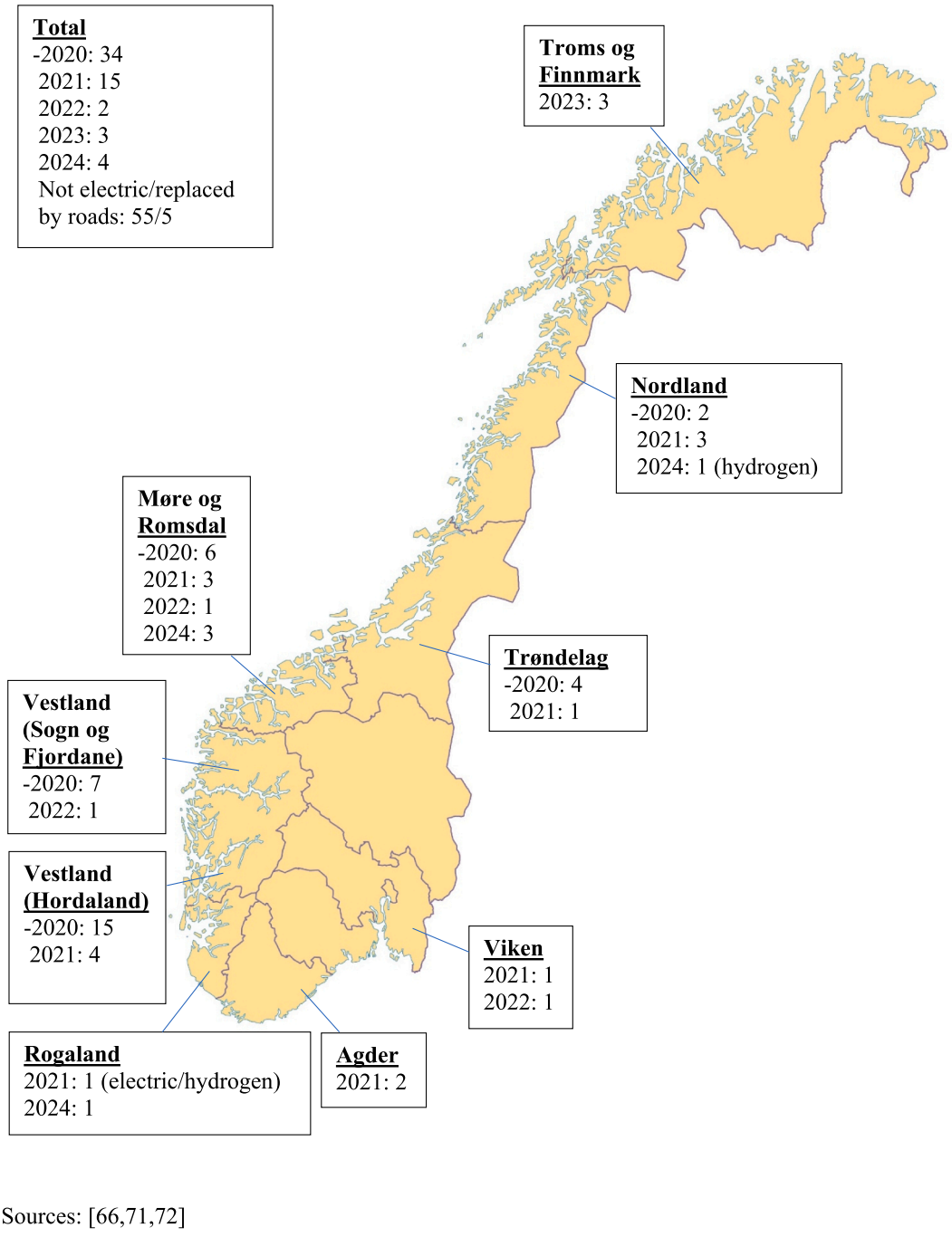

Fig. 1. County-by-county overview of the progression of electrification of Norwegian ferries [66,71,72].

market creator and transformer through various agencies and support schemes. Finally, we argue that the relative lack of strong opposing vested interests in combination with an oil shock created favorable conditions for structural change.

5.1. The Norwegian ferry innovation system

While a system of innovation is to some extent always a theoretical abstraction imposed on the empirical material by the authors, the empirical research made it clear that the Norwegian ferry actors are close-knit and collaborative to an extent that justifies the label system of innovation. We find ample evidence that the Norwegian ferry innovation system acted as a cluster characterized by close collaborations, transparency, trust, and knowledge sharing. These conditions and distinct features of the system have been crucial for the transition to electric ferries. The Norwegian system conforms to what Edquist [40] labels a networking innovation system, characterized by knowledge transfer through cooperation and collaboration and by long-term network arrangements.

5.1.1. Main actors and interactions in the ferry innovation system

To highlight the stakeholder linkages within this transportation segment, in Fig. 2, below we have graphically mapped out the key stakeholders, displaying how they are linked and how they operate. In the following, we highlight why some of these interactions were vital in enabling the accelerated transition toward electric ferries in Norway.

The NPRA handles the operation of the ferry crossings that are part of the national roads system, while the counties have responsibility for

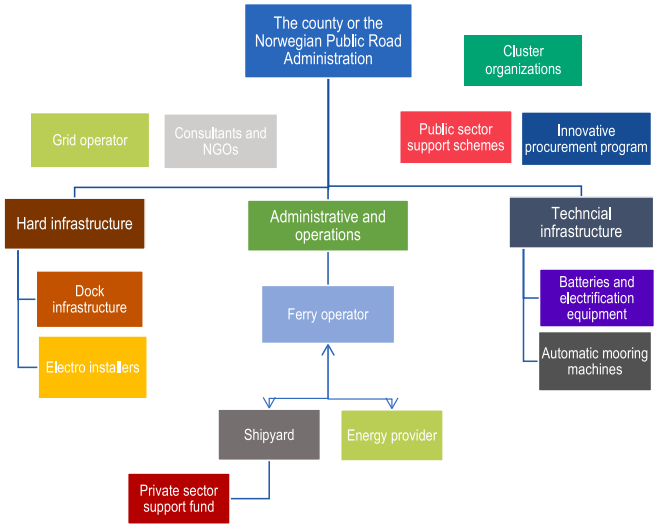

Fig. 2. The Norwegian ferry innovation system.

ferry operations affiliated with county roads. Their responsibilities vary slightly but involve setting public tenders for new ferry contracts, while some also own and run dock infrastructure. The management of public transport varies slightly but generally the counties have created public transport administrative companies that run the day-to-day operations. These can be either fully-owned or co-owned companies with neighboring counties, which in turn procure ferry operators to operate the ferry crossings. Appendix C shows the ownership structure of these companies. The counties and the NPRA also make use of consultants to map energy needs to evaluate whether grid upgrades will be needed. Especially for remote ferry crossings, which do not necessarily have the grid infrastructure and capacity needed to sufficiently charge the ferry batteries, this is a challenge. Operators bid on contracts that usually last 10 years through tenders set by the county or the NPRA. The biggest operators are Fjord1, Norled, Boreal, Torghatten, FosenNamsos Sjø, and Bastø Fosen. As the transition toward electric ferries has progressed, fewer ferry operators own dock side infrastructure. Therefore, it is becoming more common that operators only pay for fuel/electricity of their operations. Operators calculate substantial fuel cost savings from electric propulsion, even if the ferry itself is currently more expensive to purchase. This however is slowly changing as battery costs are coming down and shipyards build more electric ferries.

5.1.2. *A unique Norwegian culture*

The close relationships between the actors within the Norwegian maritime networks are thoroughly documented by Hessevik [34]. While Hessevik's study is more about the lobbying influence of these networks than their collaboration, she leaves little doubt that they work closely together as a cluster whenever this is beneficial.

The line that sums up the network the best, and one repeated in different versions by several respondents, is that the maritime actors collaborate when they can (through clusters and private–public partnerships) and compete only when they have to. Several respondents referred to this as a distinctly unique and specifically Norwegian culture.

The respondents close to the decision-making processes have been very clear about the transparency between stakeholders, which has contributed to process-learning and sharing of best-practices. The county and public transport administrative company respondents told us that the electrification of ferries completely changed the process and the amount of involvement from the procuring side, from everything to do with new charging infrastructures to the fact that they needed updated knowledge and capacity to understand and feel competent enough about the new technologies compared to a traditional ferry. The general sentiment is that although there have been bumps in the road and numerous challenges, it has been a rewarding and continuous learning process for everyone involved.

The respondents are clear that the stakeholders have been interested more in learning, dialogue and sharing, than secrecy and competition. There is a lot of interaction between large and small industrial actors, and information and experiences are being shared. The ferry actors explicitly confirmed that one thing they think is unique about Norway is how the whole value chain cooperates.

Thus, the value chain is central to the system. The ferry value chain is mostly local and linked together, including battery production and system integration. This has made the whole sector more willing to embrace electrification and technology development. One of the respondents added that this also applies to the state, including its support agency Enova. There is enormous value-added from the fact that the entire value chain is within Norway, making it far easier to create market change. Thus, the closer knit the cluster is, the more attractive it is also for the state to be involved, among other factors because of the potential for Norwegian technology development and job creation. One respondent added that not only is it easier and faster to relate to partners that speak the same language and come from the same business culture, but in many cases the distance between the actors is so short that they can physically see each other. This greatly improves the speed with which actors can coordinate and jointly move in new directions, such as building battery ferries with state-of-the-art dock-side charging infrastructure. Another respondent was clear that the physical proximity between Siemens' battery factory in Trondheim and the technological knowledge cluster constituted by The Norwegian University of Science and Technology and SINTEF (one of Scandinavia's largest applied research institutes) has been essential.

Finally, several environmental NGOs play a central role in the ferry innovation system. Zero especially, has been invaluable, through its persistence in pushing policymakers to take action on climate solutions and through the facilitation of dialogue at forums and conferences, such as the annual Zero conference where policymakers, industry, NGOs, and academia meet and engage in networking, knowledge sharing and showcasing of best-practices. This represents a core feature of the Norwegian innovation system in general, and in the Norwegian ferry innovation system in particular.

In sum, close collaboration, knowledge sharing, and high levels of trust between the actors, combined with the early market dialogue between the NPRA, the counties, ferry operators and their supply chains, was reiterated time and again by our respondents as important mediators of success. The ferry innovation system thus created conditions that allowed for an accelerated transition to electric ferries.

5.2. *Beyond the innovation system: A Norwegian entrepreneurial state*

5.2.1. *Active market creation and transformation through public procurements*

To fully understand the Norwegian transition to electric ferries, it makes sense to start with the technology-neutral development contract that yielded the world's first electric ferry. The contract was issued by the NPRA in 2011, "with the aim of stimulating to zero or low emission technology in the developmental, yet commercial, tendering process." [7]. All respondents highlighted the Ampere tender as the key event that sparked the ferry transition. As the county respondents emphasized, ferries constituted a substantial source of emissions and had to be decarbonized for emission targets to be reached. Thus, the proof-of-concept and experience from the Ampere process meant that ambitious climate targets set by politicians could more feasibly be pursued.

Hessevik [34] emphasizes how the actors of the innovation system actively lobbied for the state (both national, regional, and local levels) to take a more active role in terms of procurements. The importance of procurements was also mentioned by many of the respondents, as well as the literature [7,9,31]. The public transport administrative company respondents clarified that while everyone wanted to find the most

environmentally friendly solution at the lowest possible cost, it is expensive to be a first mover. The interviews made it obvious that there had been a lot of discussion within the counties on how to best transition ferries toward more climate-friendly solutions. This led to a range of approaches. Some counties explicitly stated in their tenders that the operators' bidding needed to provide a battery-electric ferry, while others set absolute emission limits or eligibility specifications and otherwise maintained technology-neutrality. Some counties stated that they would prioritize the most polluting crossings with the largest budgets first, thus lowering the technology risk, while others opted for retrofit solutions on existing crossings. One respondent told us specifically that their county did not want all their ferry crossings to be first-generation electric ferries. Another added that they really had to make sure that the tender specifications were made with technology development in mind, as the battery technology is improving so fast that one feared locking in solutions that might soon be obsolete. Thus, the decision-making process was neither clear-cut nor simple. Crucially, this led to an innovation in the procurement contracts: one county added a climate bonus in one ferry procurement tender, giving the owners an incentive to lower the climate impact over the length of the contract, thus creating a dynamic, rather than a static, procurement. These are examples of how national policy and tender logic were implemented regionally and locally by actors on the ground.

Part of the role of the state as facilitator has been the active construction of meeting places between the industry and the public sector, linking actors that would otherwise not have engaged with each other, both nationally and on the county level. Hessevik [34] describes the inclusion of the NPRA in one of the major shipping networks. One of our respondents emphasized the importance of tying the entire system together, not just the industry. Another respondent hailed the importance of the in-between space between the business world and the public sector, linking procurements with the entire value-chain of actors. In this in-between space we find initiatives like the 'National Programme for Supplier Development', which has been instrumental in assisting public procurers accelerate innovations and develop new solutions through the strategic use of public procurement and by creating market opportunities for these solutions. The program is a broad collaboration between the public and the private sector [73].

It was underlined by several respondents that many of the solutions required for successful electrification involve too many actors for electrification to just happen by itself. Without working with the entire value-chain, including the financial sector, change is unlikely. This applies especially to the grid and dock-side infrastructure for the ferries, which several respondents described as often overlooked. For all practical purposes, expensive infrastructure upgrades are necessary for electrification, especially in remote areas and locations where ferry docks are far away from the main gridlines. Dock-side battery banks and longer scheduled charging times are among the options to offset some of these costs. Battery banks can also be utilized as grid assets to provide peak shaving or demand response services for local distributed system operators.

5.2.2. *Politically staking out a low emission course*

Through the strategic use of public procurements, the public sector created a market for low-carbon ferry solutions. Additionally, the strong political signals from Prop. 78S. [61], ambitious county climate targets, and a vocal NPRA, made it clear that sectors with public stakeholders would move toward low-carbon solutions, thus assuring the private sector that their new solutions would have a sizeable market. This led to several key developments and subsequent decisions by Corvus Energy and Siemens to build two maritime battery factories in Norway. Several of our respondents highlighted that the link between the ongoing electrification of the ferries, strong political commitment, and access to cost-competitive renewable energy were all key determinants of the decisions to place the battery factories in Norway, and of the decision to produce batteries for the maritime sector in the first place. Here we see a clear example of the confluence of climate policy and industrial policy.

It is no understatement that Norway created a market for maritime battery solutions that has contributed to an ongoing battery-electric revolution in the maritime sector, not just in Norway, but globally [74]. The technological spillover from the ferries and other early adopters of these technologies into other segments of shipping has clearly motivated suppliers and shipyards across the value chain to commit considerable resources to clean-tech related capacity. Additionally, based on our conversations with the industry actors, what was eminently clear was how big of an advantage it was to be located in a region and in a country which could showcase first-hand the utilization of the technology in harsh Norwegian climate, with the added benefit and commercially attractive prospect of producing the batteries with clean renewable power.

The instrumental role of the NPRA looks to be replicated with Norway's recent endeavors into the maritime hydrogen space. The agency has adopted the same pioneering role for the first Norwegian hydrogen ferry (fall 2021) and the hydrogen solution for the Vestfjorden- crossings in Lofoten (2024). The institutional capacity and know-how of the NPRA is benefitting counties and the national maritime scene tremendously, and it will be a key agency in the much tougher challenge of decarbonizing high-speed ferries, expected to start after 2024. Being a national agency with stronger governmental control and fewer budget restrictions than the counties, there was a consensus among the respondents that the NPRA has been crucial for the electrification of ferries. Essentially, the agency has been a key transition actor for the Norwegian entrepreneurial state.

5.2.3. *A support system rigged for change and market transformation*

The Norwegian climate and energy support agency, Enova,[11] is one of the central economic instruments through which the government reduces GHG emissions and supports and accelerates the development of climate and energy technologies. Arguably, Enova is a part of the innovation system. Rather than categorically separating the two, we see Enova as an example that there often is no clear distinction between the state and the innovation system. Enova is an integral part of the innovation system and simultaneously one of the foremost levers for the Norwegian entrepreneurial state to support and accelerate market creation and transformation. For ferries specifically, the applicants can apply for funding from Enova for infrastructure expenses for up to a maximum of 40% of the cost. As Enova is bound by EFTA regulations on state support, the project must show that the funding leads to innovation or measurable results that would not otherwise have occurred.

Enova's mandate has changed considerably over time, from an original emphasis on energy/emission savings to now allowing it to focus on market transformation possibilities. To our respondents, this shift has allowed Enova to think more strategically and longer-term with a stronger presence and focus on supporting a green maritime shift and battery supply chain in Norway, two areas that the electrification of ferries benefit from.

As an additional de-risking support scheme, Enova administers the PILOT-E funding scheme, which has contributed to significant advances in the development of zero-emission and autonomous ferries and has contributed to creating new maritime-related industry. The program provides financial support for "fast-track from concept to market" for projects that deploy and develop "new environment-friendly energy technology products and services to help to reduce emissions both in Norway and internationally" [76], another sign of the active participation of the state. The support agency respondents also highlighted that the support schemes are focusing on projects that will accelerate the transition toward cleaner, more competitive solutions in the maritime sector and that Enova seeks to support solutions that can stand on their own feet and not rely on government subsidies once competitive in the

[11] Owned by the Norwegian Ministry of Climate and Environment [75].

market. Additionally, suppliers and ship-owners can apply for funding from the NO_x fund, which is the result of a 2008 agreement between the state and the major business associations to reduce NO_x emissions.[12] The fund has contributed to several ferry-electrification projects [77]. Innovation Norway is another state program that has provided support for R&D and development funding on both sides of the procurement process.

5.3. Absence of strong vested interests to oppose transition

The ferry case is in many ways a showcase of how to create win–win situations among key stakeholders. The fact that it happened in a hard-to-decarbonize sector makes it even more interesting. Looking at the case through a Schumpeterian evolutionary economy lens highlights that structural change, here a ferry transition, is considerably easier when there are few structural barriers or opposing vested interests. In the ferry case, existing actors were not replaced and made obsolete by competing actors with rival technologies. Instead, they were able and willing (and aided by the state) to pursue the necessary transition—in Kelsey's [53] words, to go from transition losers to convertibles. At every conference attended, the sentiment among the shipping industry actors was that the industry saw the shift toward lower emission solutions as a strategic priority. This was echoed by our respondents. The unique culture among the stakeholders, mentioned in several interviews with both industry and public support system actors, is integral to why Norway was able to bypass some of the inertia and resistance that usually comes from vested interests facing a transition. These claims were backed up by comments and presentations given by industry and public sector stakeholders at conferences and seminars. As one industrial manager put it; "If the public sector orders ferries with high climate ambitions, the industry will be ready to provide it, with the technological and price developments getting to a favorable point for competitiveness." Given Hessevik's [34] account of the lobbying power of the maritime sector, the short-term interest of the sector could easily have been to stick with familiar solutions. Instead, the industry recognized electrification as necessary and something that might produce long-term competitive advantage. None of our respondents noted any efforts on the part of the industry to influence policymakers to abandon or slow down electrification efforts. Instead, we saw widespread cooperation between industrial actors, the support system, and the state to find solutions to the mutual benefit of all the actors in the system. Thus, lobbying power was not used to block change but to actively appeal for the need for the public sector to create the necessary green markets, develop infrastructure, and remove system barriers for cleaner shipping. The outcome was that the public sector tendered for highly ambitious ferries with large emission savings and that the industry developed and provided them.

To the extent that vested interests mattered, they did so in the sense that it was becoming ever more obvious that the sector was steadily losing market shares internationally, becoming more vulnerable, which was impressed upon the state by the unions [78]. The maritime sector argued forcefully that the contribution of the state would safeguard the national industry and make Norway into a showcase for the world [34]. For the state, a maritime energy transition took on greater importance once it became a matter of merging climate and industrial politics.

5.4. The oil price shock as accelerator

Not only did vested interests not oppose change, they were, in a very fundamental sense, given a stimulus to transition after the crisis caused by the oil price drop in 2014, which resulted in a near drying-up of contracts for newbuilds. A recent report highlights just how reliant the yards were on orders from the offshore segment. There were more than 2,000 offshore-related newbuilds both between 2006 and 2010 and 2011–2015, but they fell steeply to 760 between 2016 and 2020, resulting in an order book of only 363 at the end of 2020 [6]. In the same period orders for ferries and high-speed ferries increased from 562 (2006–10) to 817 (2016–2020). One respondent was clear that numerous shipyards would have been in serious trouble if it were not for the new battery ferries. It was a stroke of good luck for the shipyards that there were ferries to be built. At the same time, without the oil price shock, there would have been far less of an incentive for the shipyards to reform as they would have been running at full capacity because of orders from the petroleum sector. Thus, with respect to creative destruction, the oil price crashing was a blessing in disguise, with electrification partially a result of the drop in demand from petroleum [74,79]. The oil price crash also prompted the aforementioned broad coalition across party lines in 2015 to pass a motion in the parliament obligating the government to present measures for how to increase the use of low- and zero-carbon technologies in the maritime sector [61].

The oil price crash effectively meant that the industry had to undergo a green industrial restructuring, but the crisis also constituted an opportunity and a lifeline. Many shipyards did not even build ferries until the transition toward electric ferries, thus making it a costly affair with plenty of new and challenging integration issues to be solved. While building new capacity and overcoming integration challenges with battery-electrical ferries implied steep learning curves and unintended costs, the industry actors amongst our respondents were adamant that electrification and other clean-tech technologies will pay dividends, as more maritime segments adopt these low-carbon solutions.

6. A case of an accelerated transition

Ferries are an integral and traditional part of the Norwegian road system and the path to their ongoing electrification is a fascinating mix of active governmental policy and regulations, support scheme alignment and private sector initiatives that, together with an unexpected and beneficial crisis, combined to accelerate the transition. Most of the respondents were clear that the process that led to the first electric ferry, Ampere, was very much politically driven, and that the experience and momentum from Ampere created a snowball effect. In general, our respondents asserted that the shipping industry and its suppliers were an active part of the directional shift toward cleaner solutions and that the shift was supercharged by the dramatic fall in oil prices, as many shipyards were forced to diversify and look for new markets.

Shipyards produce local revenues and jobs, which makes them politically potent. Yet, the transition did not happen because of the crisis but accelerated it, as Ampere had preceded it by several years. However, no oil shock would arguably have resulted in vested interest opposition from a maritime sector still prioritizing lucrative orders from the petroleum sector, thus delaying the transition. The crisis thus created a policy window for politicians and industry to combine climate efforts and industrial development in pursuing a cleaner and more competitive maritime sector, in the process also facilitating a domestic maritime battery supply chain and erecting transition-enabling infrastructure. The merging of climate and industrial politics was key to the acceleration of change.

The case fits Mazzucato's [18] notion of an entrepreneurial state. The Norwegian ferry case is an example of an accelerated transition where the state not only acted as "de-risker" of the first pilot projects, but also acted entrepreneurially, bringing industrial and public actors together, creating and shaping a new market through public procurement processes and hands-on facilitation, and coordinating the construction of the enabling infrastructure needed for this market. One thing this case clearly shows is the importance and the potency of active, knowledgeable public procurers that engage in dialogue with the suppliers and industry to create well-specified tenders. In short, the public sector envisioned the risk space and operated within it to create and

[12] Between 2008 and 2019 the fund awarded NOK4.4 billion for NO_x-reducing projects and measures [77].

accelerate the transition, and the private sector responded and provided solutions. This all represents a departure for Norwegian climate, energy and industry policy, which since the 1990 s has been distinctly market-oriented, with industrial neutrality and cost-effectiveness as key notions (e.g. [80,81] (the other noticeable expectation being the transition toward electric vehicles).

Our respondents amongst the procurers were clear that creating and transforming the new markets required more than simple market-based solutions; instead, it required a whole mix of policy, regulations, and incentives. Additionally, they suggested that close market dialogue and identifying win–win situations between the public, private and academic sectors were key parts of getting the transition underway. Our industrial respondents suggested that they primarily needed assurances that there would be a market for the new solutions they created. In that sense the parliamentary ruling for low- and zero emission tenders, combined with ambitious climate goals, gave the industry a very clear direction. While a ferry transition is probably inevitable in the long run, market-based solutions alone would not have produced the present transition.

6.1. Four success factors leading to the electrification of ferries in Norway

The ferry case enables us to identify success criteria for the transition organized loosely around the four theoretical explanations presented earlier:

6.1.1. An innovation system characterized by close collaboration and extensive dialogue among stakeholders

The stakeholders in the ferry segment, and by extension the maritime industry cluster, are small and part of larger clusters. The actors collaborate when they can and compete when they have to. Both public and private stakeholders cooperate, learn and lean on each other, which creates a unique environment where solutions are invented and refined, increasing the chances of eventual success. The extensive dialogue between stakeholders in the ferry innovation system is highlighted by nearly all our respondents as a massive success criterion for the accelerated transition toward electric ferries.

6.1.2. An interconnected innovation system and an active entrepreneurial state

The range of support schemes and process-knowledge in various programs that facilitate knowledge sharing, dialogue, and provide financial support, have been vital to the transition. The shift in Enova's mandate toward a stronger focus on market transformational goals and market creation was a contributory factor to the accelerated transition, with an added strategic focus on supporting national competitive supply chains within the Norwegian maritime sector and battery production.

6.1.3. An entrepreneurial state and ambitious climate targets set the direction for a decarbonized ferry sector

The Norwegian state apparatus pulled in one direction to transform the market. This made it possible for regional and local stakeholders to act ambitiously. Secondly, the de-risking actions of the Norwegian counties combined with the NPRA taking on responsibility, coordination and costs for dockside infrastructure, assisted by the public support system, also contributed to the ferry operators' ability to compete with low-emission solutions in new ferry tenders. The procurers in both counties and NPRA were aided by ambitious climate targets and a strong parliamentary ruling. This created a clear direction and opportunity space for ambitious tenders, which eventually solidified low emission solutions as the clear preference in the ferry segment.

6.1.4. Undermining resistance from vested interests by transforming would-be transition losers into convertibles and making the best out of a crisis

The focus on developing competitive national supply chains by leveraging public procurements as part of market creation and transformation is a clear success criterion and has helped transform some would-be transition losers into convertibles, thereby conceivably undermining resistance from vested interests. Instead, vested interests used their lobbying power to accelerate change, rather than attempting to slow it down. Finally, stakeholders in both the public and the private sector used the window of opportunity created by the oil price crash to transition to a more competitive and cleaner maritime sector.

7. Concluding remarks

The electrification of Norwegian ferries is still not complete, and obviously, until fossil fuel lock-in has been replaced by electric lock-in, any change is reversible. Recently, Norwegian shipyards have lost market shares internationally, thus pressures are mounting to make sure that the clean-tech capacity these yards have acquired is not lost to foreign competitors [6,78,79]. Electrification and costs related to grid upgrades and new dock- and charging infrastructure has also triggered a rise in ferry ticket prices, with subsequent protests and demands for ticket price cuts, prompting the government to cut ticket prices by 25% over the national budget [82,83]. Also, Enova recently announced that it is scaling back charging infrastructure support schemes, citing the foothold that electrification has gained in the market [84]. Thus, the true test of the continued transition toward electric ferries might still lay ahead. This does not mean that there is nothing to learn from the electrification of ferries. This is a story of political will and facilitation combined with an absence of resistant vested interests—absent partly because of a severe oil shock. With orders from the petroleum sector nosediving, the politically induced push for a more climate-aligned maritime sector gave the shipyards and the supply chains a welcome break and a crisis-avoiding outlet. The government could claim to be saving both jobs and the climate through a public support system that used active public procurements to strategically facilitate market creation and transformation and building national supply chains. In summary, the electrification of Norwegian ferries shows that transitions can, in fact, happen quickly.

We show that electrification was testament to a potent mix of the alignment of climate and industrial policy goals through the means of public–private partnerships, with facilitated dialogue and the use of public procurement as a tool for market creation. The case is also a reminder that transitions can be fast in the absence of opposition from vested interests, especially when potentially refractory interests are given incentives to adapt and transition to a new paradigm.

Mowery [85] warns that we cannot simply cut and paste lessons from one mission-oriented program to another. They all have their own specificities, and the Norwegian case is no exception. Norway has a long and proud shipping and maritime history, thus there are strategic and historical reasons as to why both the Norwegian public and private sector have been eager to take a leading role in a green maritime shift. Also, Norway's electricity sector is close to 100% renewable. This means that Norway, more eagerly than other countries, has looked toward transportation for sectors that are conducive to emissions cuts. Furthermore, Norway's renewable prowess has made the country attractive for energy-intensive production, such as batteries. Thus, there are several reasons why we would expect Norway to be a frontrunner in the electrification of shipping.

Yet, we believe that the Norwegian case provides key insights that can be transferred to other countries as well in the pursuit of energy transitions in other hard-to-decarbonize sectors. Besides having a well-functioning innovation system and a state that actively facilitated structural change, one of the lessons is that finding national competitive advantages in the energy transition is increasingly important as policymakers and public support systems allocate scarce resources in their attempts to identify sustainable growth impulses. Linking the green maritime shift with a national chain of suppliers and battery providers has aligned climate and industrial policy goals. This has accelerated the process of change. Other countries and regions may have different

competitive industries, sectors, and niches conducive to an energy transition. This case shows how Norway did it with ferries.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2021.102282.

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