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Norwegian ship-owners' adoption of alternative fuels

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ABSTRACT

The shipping sector's rising greenhouse gas emissions are often considered "hard-to-abate". Some ship-owners have recently adopted or started to consider the adoption of alternative fuels, but systematic studies of this are still lacking. We address this gap by studying how ship-owners differ in both actual and intended adoption of alternative fuels. We analyze data from a unique survey with 281 ship-owners in Norway, a major ship-owning country and center for maritime technology development, with descriptive statistics and analysis of variance. We find early adopters among large and established ship-owners in offshore, international cargo and domestic passenger shipping segments, which are often subjected to specific contractual demands for alternative fuel adoption. Laggards were typically small and young ship-owners operating in shipping segments where demands for alternative fuel adoption are weak. Our findings also suggest that firms' business strategy and financial and knowledge resources may have relevance for ship-owner's adoption of alternative fuels. Our study has implications for national and international policymaking, highlighting for example how contracting mechanisms can be an effective tool in incentivizing the adoption of alternative fuels.

1. Introduction

Accounting for 2.9% of carbon dioxide emissions, the shipping industry is generally considered to be a "hard-to-abate" sector (IMO, 2020a) due to the lack of viable technological alternatives to fossil fuels, a situation also found in heavy transport and aviation (Davis et al., 2018; Victor et al., 2019). Shipping's emissions are "projected to increase from about 90% of 2008 emissions in 2018 to 90–130% of 2008 emissions by 2050 for a range of plausible long-term economic and energy scenarios" (IMO, 2020a: 4). In 2018 the UN's International Maritime Organization (IMO), which regulates environmental protection for international shipping, set the target of halving greenhouse gas (GHG) emissions by 2050 compared to 2008, whilst pursuing aims of phasing them out entirely by the end of the century (IMO, 2020b). In COP26 (Glasgow) in 2021, a declaration calling for net zero-emission shipping by 2050 was signed by a group of nations led by Denmark, while 22 nations signed the Clydebank declaration regarding the establishment of green shipping corridors (Siglar, 2021).

While various energy efficiency measures hold potential to abate emissions (e.g., Adland et al., 2018; Poulsen and Sampson, 2020; Rehmatulla and Smith, 2015), the achievement of ambitious GHG goals critically depends on widespread adoption of low- or zero-carbon fuels and energy carriers ('alternative fuels' in this paper),[1] not least due to expected growth in shipping demand (IMO, 2020a; Psaraftis, 2019; Traut et al., 2018). Alternative fuels vary substantially in terms of production, distribution and use (DNV GL, 2016; Mäkitie et al., 2020a), and also in terms of compatibility with existing maritime technology and fuel infrastructure.

Early adoption is critical in driving the progress of innovation in alternative fuels in their emergent phase (Linton, 2002). Experimentation with and implementation of alternative fuels create learning effects, enable incremental improvements, and reduce technological uncertainty regarding how alternative fuels function in practice. Early adopters create markets for the providers of novel technologies and fuels, encouraging further technological development as well as investments in the infrastructure needed to produce and supply alternative fuels (Kemp et al., 1998). This in turn reduces the barriers for further adoption. Hence, creating understanding of who the early adopters are, who are the ones slower to follow suit, and what are the critical hurdles and drivers for alternative fuel adoption is thus of high importance for

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[1] Some energy carriers, such as batteries, are not "fuels" in the commonly used meaning of the word. In this paper we however have chosen to use the term "alternative fuel" as a short catch-all term for all low- or zero-carbon fuels and energy carriers in shipping.

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governance action seeking to support energy transitions (Bergek and Mignon, 2017).

Ship-owners play a key role in the choice and adoption of ship designs and propulsion systems when contracting new ships (Poulsen et al., 2021). Their views on the adoption of alternative fuels therefore have an important bearing on alternative fuel innovation. To the best of our knowledge, ship-owners' alternative fuel adoption – and their variation – have not been subjected to systematic studies. We address this knowledge gap on through an exploratory study of the following research question:

How do ship-owners differ in adoption of alternative fuels?

A wide range of candidate alternative fuels exist, including battery-electric and hydrogen, liquefied natural gas (LNG), various types of biodiesel, liquefied biogas (LBG, biomethane), and ammonia and methanol (ABS, 2021; DNV, 2019b; International Transport Forum-OECD, 2018). Moreover, synthetically produced diesel or methane (using e.g. hydrogen, gas or biomass as raw material) are options to extend the lifetime of the existing energy technologies, machinery of current vessels and infrastructure. Adoption of alternative fuels among ship-owners however remains very limited. We summarize (non--exhaustively and in a simplified manner) in Table 1 how some of the most relevant alternative fuels differ in terms of their maturity, requirements for adaptations in ship-designs and operations, availability and investment needs concerning infrastructure for production, storage and distribution (for a more detailed overview, see e.g. DNV GL, 2019a) – and their environmental benefits. The latter depends on how the fuel is produced (e.g., hydrogen produced with renewable energy or from a fossil resource, types of biomass used for generation biofuels, etc.), how it is used (e.g., in a combustion engine or with fuel cells), or other technologies that handle fuel-specific issues (e.g., scrubbers).

An emerging literature on maritime environmental governance has pointed out how the lack of strong and enforceable global regulation, poor alignment of interests among shipping stakeholders, and low visibility of environmental issues hamper environmental upgrading in shipping, including emission abatement (Lister et al., 2015; Poulsen et al., 2016). For instance, in the international tanker and dry bulk shipping segments, market drivers in the form of cargo-owners' greening demands have generally been weak (Poulsen et al., 2016, 2021). In the Norwegian context, however, public procurement was decisive for the introduction of battery-electric systems in ferries, and customer demands from the energy company, Equinor, for the adoption of battery-electric systems onboard offshore supply vessels (Bach et al., 2020).

Beyond market drivers, the nature of shipping segments also influences alternative fuel adoption. Shipping is highly heterogenous, ranging from large oil tankers and container ships in deep sea trades to small fishing boats and short haul ferries (Poulsen et al., 2016). The operational profiles, power needs, sailing distances, and whether vessels operate on fixed routes or not, differ drastically (DNV GL, 2016). So do market conditions for instance in terms of lengths of contracts (Bergek et al., 2021). Thus, some alternative fuels are relevant in some shipping segments, while not in others. Battery-electric solutions, for instance, may be seen as suitable for short haul ferries, but are currently only relevant for efficiency and 'peak-shaving' purposes in deep sea shipping due to their low energy density (DNV GL, 2019a). Finally, vessel types across segments differ with regards to the feasibility of retrofitting to accommodate alternative energy solutions (requiring e.g. new onboard space-consuming energy storage) or if newbuilds are needed (Steen et al., 2019).

In a study of environmental management strategies in shipping companies, van Leeuwen and van Koppen (2016) found that ship-owners predominantly employ 'a crisis oriented' strategy, aiming to comply with environmental regulation, while Rojon and Dieperink (2014) found ship-owners preferring a wait-and-see strategy in relation to adoption of wind propulsion due to risk aversion. However, Alger et al. (2021) found large shipping companies pushing for higher environmental standards to raise costs for small and midsized competitors. Stalmokaitė and Hassler (2020) found that incumbent shipping companies in the Baltic Sea region are gradually implementing proactive innovation strategies for decarbonization in response to broader socio-political pressures. Saether et al. (2021) suggest that ship-owners with a long-term orientation tend to be more active in green innovation and strategy. Recent public decarbonization commitments by major ship-owners (e.g. DFDS, 2020; Maersk, 2019) also indicate that some ship-owners are showing increasing interest towards the adoption of alternative fuels. On a general note, it also seems clear that the management-oriented literature has focused on shipping companies operating for instance within container and bulk market segments, whereas for example the fishing vessel segment has received little attention (Greer et al., 2019).

To explore how ship-owners differ in alternative fuel adoption, we use data from a unique survey among Norwegian ship-owners. Norway is a major ship-owning country and is among the global maritime technology leaders (Tenold, 2019). It also has a complete maritime cluster which has been active in developing environmental innovations (Mäkitie et al., 2020b). Norwegian ship-owners were major frontrunners

Table 1
Alternative fuels for shipping - characteristics and benefits. Based on (DNV GL, 2016, 2017), Steen et al. (2019), ABS (2021).

	LBG (biomethane)	Biodiesel (FAME & HVO)[a]	Electric (full)	Electric hybrid	Hydrogen (carbon neutral)	LNG	Ammonia (green)	Methanol (green)
Reduction of greenhouse gases[b]	High	FAME: low HVO: high	Very high	Moderate	Very high	Low	High	High
Reduction of NO_x	High	Low (increase)	Very high	Moderate	Very high	High	High	High
Reduction of SO_x	Very high	FAME: low-moderate HVO: Very high	Very high	Moderate	Very high	Very high	High	High
Vessel adaptation	Moderate-high[c]	Low	High	Moderate-high	High	Moderate-high	High	High
Technological maturity	High	High	Moderate	Moderate-high	Low	High	Low	Low
Availability (incl. infrastructure production, bunkering/ charging)	Low	Low	Moderate	Moderate	Low	Moderate	Low	Low
Applicability in different shipping segments	All	All	Short routes	All – esp. variable energy demand	Short to mid-range routes	All	All	All

[a] FAME (fully acid methyl aster) biodiesel can only be used as a blend in regular marine diesel in small amounts (~7%). The potential environmental benefits are therefore limited. HVO (hydrotreated vegetable oil) can be used as a standalone fuel (as well as a blend with fossil marine diesel) in existing marine diesel engines and distribution and refuelling facilities, and thus has higher potential environmental benefits. In the rest of the paper we however discuss both under the term "biodiesel".

[b] The overall carbon emissions of fuels depend on e.g. the type of energy, raw materials and production methods used in their lifecycle. In this table we consider the emissions released when consumed in shipping.

[c] LBG can however be used in existing LNG vessels.

in adopting LNG propulsion systems during the first decade of 2000s, and in 2021 about 40% of all world's battery-electric vessels operate in Norway (Maritime Battery Forum, 2021). Moreover, the first hydrogen vessel in the world is expected to start operating in Norway during the winter 2021–2022. Policy has been an important driver in this burgeoning transition. The Norwegian government aims to halve domestic shipping and fishery emissions by 2030 (compared to 2005) (Regjeringen, 2019). The Norwegian Shipowners' Association has furthermore pledged to achieve climate neutrality by 2050 (Rederiforbundet, 2020). In their abatement aims, both the government and Shipowners' Association thus go beyond e.g. the IMO GHG emission reduction targets. Stricter emission regulations will apply to cruise ships visiting Norwegian fjords, and several Norwegian ports use their port fee systems to incentivize adoption of alternative fuels (Bjerkan et al., 2021; Damman et al., 2019). In sum, because of its frontrunner role, Norway offers an opportunity to provide early insights into alternative fuel adoption in shipping, as a notable number of Norwegian shipowners either already have experience from the adoption of alternative fuels, or may be experiencing mounting pressures to do so due to e.g. tightening national environmental policies and/or market demands.

As will be made clear in the sections that follow, our survey covers firms which have already adopted, intend to adopt and do not intend to adopt alternative fuels. Intentions, or perceptions, concerning future business decisions may of course change and should be treated with caution. However, they guide ship-owners' technology search activities and steer their investment decisions in certain directions, thus having important bearings on the development and adoption of alternative fuels (Borup et al., 2006). Shedding new light on such experiences and intentions, our study has implications for policymakers wishing to foster alternative fuel adoption in shipping.

The paper proceeds as follows. Section 2 outlines our methodology, while section 3 presents the results. Section 4 discusses our results in relation to previous studies, and section 5 concludes and proposes policy implications.

2. Methodology

The survey used in this paper was designed to provide knowledge regarding the experiences and expectations of ship-owners regarding alternative fuel adoption, their main drivers and barriers for this, and their attitudes towards novel technologies and environmental issues. To put these insights in context the survey also included questions related to the key characteristics and the operational environments of ship-owners. This allows us to identify groups of ship-owners with different types of adoption behavior and expectations, and to link these firm-level factors to the reported drivers, barriers, features etc. of each individual ship-owner. The survey is thus well-suited for the analysis of differences in alternative fuel adoption. The survey has also been used in a recent paper by Saether et al. (2021).

Survey questions were based on existing literature outlining key topics in the adoption of alternative fuels (see briefly presented overview in Section 1). Moreover, the question formation was informed by insights gathered from more than 70 semi-structured interviews by the authors and their colleagues with various actors within the Norwegian shipping industry (this data has been used more extensively in e.g., Bach et al., 2020, 2021; Bergek et al., 2021). An overview of the specific survey questions used in this present paper can be found in Table A1 in the Appendix.

The following section provides more details regarding this survey and how we prepared the data to answer the research question of this paper.

2.1. Data collection

The population of the survey consists of 2707 active public and limited liability companies with over NOK 1 Million in operating income that owned and/or operated sea-going vessels, as identified in Proff Forvalt, an online database of all registered companies in Norway.[2] We targeted CEOs because they have a critical say on investment decisions, including contracting of new ships and retrofitting. Some individuals act as CEOs for two or more registered companies, and we identified 2005 individual CEOs of companies with seagoing vessels. Some email addresses for firms and their associated executives were available in the Proff Forvalt database, while additional emails were gathered via phone, online searches, and contacting maritime organizations and alliances. Ultimately, we were able to identify 1045 unique email addresses.

We pretested the survey with a pilot group of practitioners to ensure comprehensibility before we distributed the questionnaire in late 2019. We requested respondents to answer on behalf of one of their associated companies to avoid multiple responses from the same individual. Individual respondents and their respective companies were guaranteed confidentiality, and they were also ensured that collected survey data would only be presented and/or published in aggregate form to prevent the possibility of individual identification. After following up by phone and email to increase the response rate we received 287 responses (28 percent response rate). Of these 287 companies, we excluded 6 which were ship-operators only (i.e., did not own ships).

Our sample is closely representative of the Norwegian ship-owner population. Specifically, our study's respondents resemble non-respondents based on characteristics such as size, age, and segment. We also conducted a *t*-test to check for differences between early and late respondents as this is an effective test for non-response bias (Lambert and Harrington, 1990). Analyzing all 96 variables in the survey, we only found one statistically significant difference at the 5 percent confidence interval (i.e. environmentally friendly operations, $p < .01$). This indicates that non-response bias is of little concern.

We asked ship-owners to estimate when they would adopt the following alternative fuels on at least one of their vessels: A) electric battery, B) liquefied natural gas (LNG), C) biodiesel, D) biogas (liquified biogas/LBG), E) hydrogen, F) ammonia and G) methanol. Furthermore, we asked survey respondents about their motivations and barriers for adoption of alternative fuels. We based our motivation measures primarily on Bansal and Roth (2000) who distinguish between three types of motivations for firms to adopt environmentally friendly initiatives, namely, *legitimation* (e.g., 'it will improve the company's reputation), *competitiveness* (e.g., 'it will provide long-term profitability') and *environmental responsibility* (e.g., it is important for us to contribute to a cleaner environment). Furthermore, we measured barriers with items inspired by literature on technological responses to environmental issues (Ashford, 1993) and innovation barriers (D'Este et al., 2012; Madrid-Guijarro et al., 2009). The barriers we measure include *economic* (e.g., investment costs are too high), *informational* (e.g., lack of information about new technologies), *supply chain* (e.g., lack of infrastructure), and *technological uncertainty* (e.g., changes in alternative fuels are difficult to predict). Finally, to gather contextual information about the ship-owners' general approach towards environmental upgrading, we also asked them about their adoption of modifications in design, maintenance, and operations related to emission reduction.

2.2. Data analysis

2.2.1. Categories of ship-owners

The adoption of novel technologies by industry actors often follows a so-called S-curve (see Fig. 1), pointing to that not all actors adopt novel technologies simultaneously. Instead, it is usually possible to identify

[2] We used the following NACE categories: A.03.111 - Marine fishing, A.03.213 - Marine aquaculture, H.50 - Water transport (including subordinate codes 50.101, 50.102, 50.109, 50.201, 50.202, 50.203, 50.204, 50.300, and 50.400), H.52.22 - Service activities incidental to sea transport, and H.52.29 - Ship brokering.

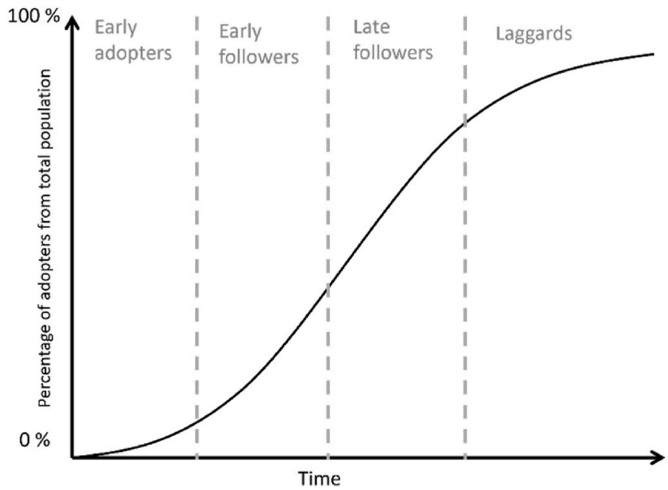

Fig. 1. S-curve of new technology adoption and different adopter categories (adapted from Rogers, 2010).

different adopter groups, such as early adopters, early followers, late followers and laggards (Rogers, 2010; Triguero et al., 2016; van Mossel et al., 2018). Early adopters are firms that seek to exploit the current and foreseen opportunities related to a new technology early on. By doing so, early adopters expose themselves to risks as there is yet much uncertainty regarding the performance of the technology, but by being pioneers they are (potentially) well-positioned to reap first-mover advantages. Early followers, on the other hand, wait for early adopters to pioneer the use of the new technology before following suit, and thus face lower risks but also likely lower rewards (van Mossel et al., 2018). Late followers are often more sceptic actors that adopt the new technology out of necessity and external pressure. Finally, laggards are typically resistant to novel technologies and thus the last, if not ever, to adopt (Rogers, 2010).

This categorization allows us to differentiate for instance what typically characterizes active and non-active adopters, what kind of drivers and barriers may be related to different types of adoption behavior, and which attitudes are common for different types of adopters.[3] This analysis will thus support further empirical investigations of adoption behavior among ship-owners in relation to alternative fuels, contributing to the explorative aim of this paper.

We operationalized this adopter categorization in terms of whether a firm had already adopted one of the investigated alternative fuels or when it intended to adopt them. If a firm had adopted at least one alternative fuel, we categorized it as an *early adopter* (N = 39). If it intended to adopt at least one alternative fuel within the next 5 years, we categorized it as an *early follower* (N = 108). If it intended to adopt at least one alternative fuel in more than 5 years' time, we categorized it as a *late follower* (N = 97). Finally, if a firm never expected to adopt any alternative fuels, we categorized it as a *laggard* (N = 37).

2.2.2. Descriptive statistics and analysis of variance

Our analyses of survey data were done in SPSS v.27. As an exploratory study with quantitative data regarding differences in adoption behavior, it was important to investigate attributes of the categories of ship-owners. Thus, we used descriptive statistics to get an overview of our sample and ship-owner characteristics. Specifically, we analyzed frequencies in the respective categories of ship-owners related to alternative fuel adoption, age and size of the firms, segment composition, and whether their operations were predominantly international or domestic shipping segments.

We also explored key differences between the four adopter categories, to shed light on the potential drivers and challenges for alternative fuel adoption by ship-owners. We followed Bergek and Mignon (2017) in using one-way analysis of variance (ANOVA) to test differences of mean scores between multiple groups. Illuminating the specific motivations, barriers, and characteristics with significant differences, we explored on the reasons for varying adoption rates. Moreover, we conducted Tukey's honestly significant difference (HSD) post-hoc tests to assess which groups differed the most.

Finally, to exemplify possible differences at the level of shipping segments, we used a *t*-test to investigate differences between the international cargo and the coastal fishing segments in motivations and barriers for adopting alternative fuels. These two segments were selected because they had the highest number of respondents, thus enabling this test to be completed.

3. Results

3.1. Descriptive statistics

Table 2 provides descriptive statistics for the four ship-owner groups in relation to their alternative fuel adoption, firm and fleet age, firm size (number of employees and vessels), segment and whether they operated primarily internationally or domestically. Early adopters and laggards are substantially different from each other across all variables, while both follower categories share some similarities with each other. It however appears that late followers are most similar to laggards, while early followers resemble early adopters. Typical firm characteristics differ also between shipping segments (see Table A3 in Appendix for details). For instance, international cargo ship-owners (largely early followers) are significantly older than coastal fishing ship-owners (largely late followers). Moreover, offshore supply ship-owners, most of which are early adopters, have significantly younger vessels than domestic passenger and cargo ship-owners, of whom a smaller portion of ship-owners are early adopters.

Fig. 2 shows the adoption in terms of different alternative fuels. Here we see that some ship-owners have already adopted electric battery, LNG, and biodiesel. In addition, these same fuels are also expected to be the most adopted alternative fuels within the next 5 years. Meanwhile, 49 percent or more of the ship-owners responded that they would never adopt biogas, ammonia, or methanol. Given the immaturity of these fuels, with lacking availability in ports as well as need for adaptation of onboard machinery and propulsion systems, this is not surprising.

Fig. 3 presents the distribution (in percentages) of adopter categories in different shipping segments (seeTable A2 and Table A3 in Appendix for more details). This figure shows that in some shipping segments, such as offshore supply, international cargo and aquaculture, a clear majority of the ship-owners belong to a single adopter category: early adopters and early followers respectively. These shipping segments thus show notable cohesiveness with similar adoption behavior between ship-owners in the same segment. However, the story is different in some of the other segments. In domestic cargo and domestic passenger segments there was more variation between the adopter categories, many ship-owners being either early or late followers, but several also being early adopters. Finally, in each shipping segment all types of adoption behavior could be found. In sum, this shows that while specific shipping segments may be linked to a certain type of adoption behavior, also notable variation within segments could be observed. In other words, different adoption behavior of individual ship-owners is likely linked to also other factors than the shipping segment. In the next section we investigate this variance further.

[3] We focus only on the adoption behavior of ship-owners in terms of alternative fuels. Hence, in this paper we do not evaluate for instance the level of environmental ambitions or the innovativeness of the ship-owners.

Table 2
Alternative fuel adopter groups among Norwegian ship-owners.

Name and size of group	Laggards $N = 37$	Late followers $N = 97$	Early followers $N = 108$	Early adopters $N = 39$
Alternative fuel adoption	***Never***	***More than 5 years*** Electric (77%) Biodiesel (45%) Hydrogen (42%) LNG (39%) Biogas (30%) Methanol (23%) Ammonia (21%)	***Within 5 years*** Electric (72%) Biodiesel (46%) LNG (28%) Biogas (13%) Hydrogen (15%) Ammonia (4%) Methanol (4%)	***Already adopted*** Electric (56%) LNG (49%) Biodiesel (26%) Methanol (0%) Biogas (0%) Hydrogen (0%) Ammonia (0%)
Number of employees in firm	***Micro and small*** 1-9 (73%) 10-49 (24%) 50-249 (0%) 250 or more (3%)	***Micro and small*** 1-9 (72%) 10-49 (25%) 50-249 (3%) 250 or more (0%)	***Micro to medium*** 1-9 (41%) 10-49 (31%) 50-249 (18%) 250 or more (10%)	***Micro to large*** 1-9 (15%) 10-49 (21%) 50-249 (18%) 250 or more (46%)
Age of firm (in years)	***Very young to middle-aged*** 1-10 (41%) 11-20 (33%) 21-40 (21%) 41 or more (5%)	***Very young to middle-aged*** 1-10 (36%) 11-20 (28%) 21-40 (26%) 41 or more (9%)	***Very young to old*** 1-10 (30%) 11-20 (23%) 21-40 (20%) 41 or more (27%)	***Young to old*** 1-10 (8%) 11-20 (23%) 21-40 (28%) 41 or more (41%)
Fleet size (number of vessels)	***Small to medium*** 1-3 (78%) 4-10 (19%) 11 or more (3%)	***Small to medium*** 1-3 (81%) 4-10 (16%) 11 or more (3%)	***Small to large*** 1-3 (53%) 4-10 (23%) 11 or more (23%)	***Small to large*** 1-3 (28%) 4-10 (18%) 11 or more (54%)
Age of fleet (in years)	***Young to old*** 1-10 (27%) 11-20 (24%) 21-30 (22%) 31 or more (27%)	***Young to old*** 1-10 (31%) 11-20 (27%) 21-30 (18%) 31 or more (24%)	***Young to middle-aged*** 1-10 (39%) 11-20 (31%) 21-30 (18%) 31 or more (13%)	***Young to middle aged*** 1-10 (51%) 11-20 (38%) 21-30 (8%) 31 or more (3%)
Domestic vs. International	***Domestic majority*** (76%)	***Domestic majority*** (72%)	***Balanced*** (53%) domestic	***International majority*** (59%)
Segments (Top 4 reported)	Coastal fishing (57%) International cargo (11%) Ship lessors (8%) Multiple other segments, each at (5%)	Coastal fishing (54%) Ocean fishing (13%) International cargo (8%) Domestic passenger (7%)	International cargo (28%) Coastal fishing (25%) Aquaculture (13%) Ocean fishing (10%)	Offshore oil & gas (26%) International cargo (21%) Domestic passenger (11%) Coastal fishing (11%)

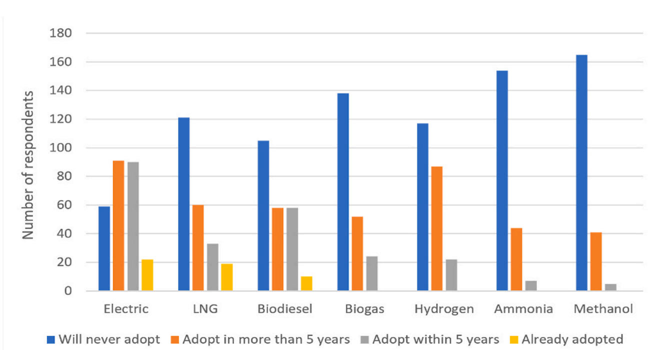

Fig. 2. Estimated adoption timeframe of alternative fuels in percent. N = 281 (some respondents did not answer all options).

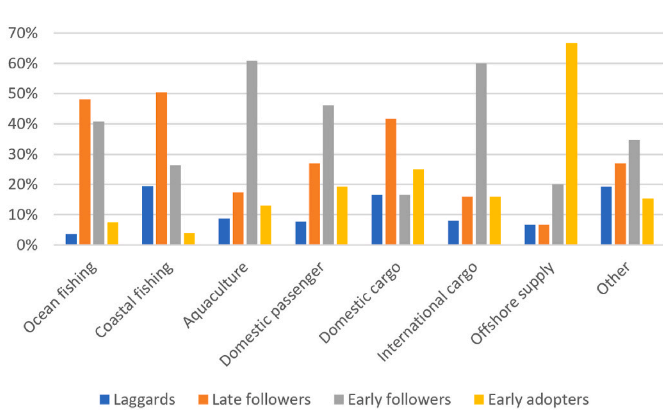

Fig. 3. Distribution of different adoption behaviour within shipping segments.

3.2. ANOVA results

3.2.1. Firm characteristics

The ANOVA results outlined in Table 3 reveal substantial differences between adopter categories. We see a general pattern of ascension from laggards to early adopters in variables, excluding fleet age which is descending. In other words, early adopters are generally larger, older, and more international in operational patterns than the other groups, and they have the youngest fleets. Early adopters are followed by early followers across variables. Finally, laggards and late followers are generally smaller, younger, have older vessels and a more domestic focus in their operations than the other two groups. Based on the post-hoc tests we can see that the laggards and late followers are often significantly different from one or both other groups, but not from each other, which is similar to the patterns observed in Table 2.

3.2.2. Alternative fuel types and modifications

We analyzed key differences in adoption of alternative fuel types with ANOVA (Table 4). From the mean scores and the F-values, we observe notable differences between the four groups, which is expected since the categories were based on alternative fuel adoption estimates. For example, the laggards are least positive for adoption of all types of alternative fuels. The groups also get progressively more optimistic heading toward the early adopters. The Tukey's comparisons show there are significant differences between at least two groups in all alternative fuels. Additionally, we see that the laggards and late followers are more often together (not significantly different from each other), while the early followers and early adopters are more often "in the same boat".

Our survey also asked ship-owners regarding the adoption of green modifications in ship designs, maintenance and operations. We use these measures to provide a point of comparison for alternative fuel adoption, since green modifications are arguably more incremental and easier to implement than alternative fuels. Tukey's comparisons provide similar

Table 3
ANOVA results for ship-owner characteristics.

	Item	Mean	SD	A) Laggards	B) Late followers	C) Early followers	D) Early adopters	F-value	Tukey HSD comparison
Characteristics	***Nr. of employees***	3.49	2.03	2.54	2.54	3.93	5.54	33.42***	A, B < C < D
	Firm age	3.34	1.60	2.73	3.00	3.48	4.36	9.63***	A, B, C < D
	Nr. of vessels	2.69	1.85	1.95	1.88	3.07	4.38	26.24***	A, B < C < D
	Age of vessels	3.49	1.85	3.92	3.83	3.33	2.67	5.10**	A, B > D
	Domestic (1) vs. international (2)	1.39	0.49	1.24	1.28	1.47	1.59	6.33***	A, B < C, D

Note. 1–7 measurement scale for all variables except domestic vs. international. Tukey's comparisons: A = Laggards, B=Late followers, C = Early followers, D = Early adopters.
****p* < .001, ***p* < .01, **p* < .05.

Table 4
ANOVA results for alternative fuel types and green modifications.

	Item	Mean	SD	A) Laggards	B) Late followers	C) Early followers	D) Early adopters	F-value	Tukey HSD comparison
Alternative fuels	***Electric***	3.79	2.00	1.00	2.84	4.92	6.05	169.46***	A < B < C < D
	LNG	2.60	2.02	1.00	1.90	3.03	4.88	39.83***	A < B < C < D
	Biodiesel	2.89	2.03	1.00	2.26	3.76	4.22	32.83***	A < B < C, D
	Biogas	1.91	1.47	1.00	1.67	2.24	2.80	11.86***	A, B < C, D
	Hydrogen	2.15	1.44	1.00	1.94	2.62	2.80	16.04***	A < B < C, D
	Ammonia	1.51	1.05	1.00	1.41	1.68	2.00	6.24***	A < B, C < D
	Methanol	1.47	1.05	1.00	1.41	1.63	1.66	3.32*	A < C
Green modifications	***Design – drag reduction***	4.14	2.36	2.70	3.60	4.72	5.35	13.02***	A, B < C, D
	Design – emission reduction	3.84	2.35	2.35	3.28	4.57	4.71	13.18***	A, B < C, D
	Maintenance	6.18	1.66	5.35	6.15	6.34	6.67	4.68**	A < C, D
	Operations	6.27	1.78	4.77	6.31	6.52	6.82	11.39***	A < B, C, D

Note. 1–7 measurement scale where 1 = will never adopt and 7 = already adopted. Tukey's comparisons: A = Laggards, B=Late followers, C = Early followers, D = Early adopters.
***p < .001, **p < .01, *p < .05.

results as in alternative fuels, showing significant results between at least two groups. Interestingly, as presented in Table 4, the results show that the alternative fuel laggards were laggards also in the adoption of green modifications, while early adopter of alternative fuel and early followers had similar roles also in green modifications. This shows that our groupings applied also to the adoption of other green improvements,

Table 5
ANOVA results for barriers and motivations to adopt alternative fuels.

	Item	M	SD	A) Laggards	B) Late followers	C) Early followers	D) Early adopters	F-value	Tukey HSD comparison
Barriers	*High investment costs (Ec)*	4.15	1.08	4.33	4.30	4.06	3.86	1.96	
	Difficult to finance (Ec)	3.85	1.09	3.93	3.93	3.86	3.60	0.82	
	Insufficient support from public policy (Ec)	3.79	1.15	3.79	3.94	3.84	3.24	3.31*	B, C > D
	Lack of information on alternative fuels (Inf)	3.39	1.17	3.44	3.69	3.34	2.71	6.36***	A, B, C > D
	We lack knowledge on alternative fuels (Inf)	3.34	1.25	3.30	3.79	3.21	2.60	9.05***	B > C > D
	Lack of infrastructure. (SC)	3.75	1.15	3.74	3.76	3.88	3.40	1.50	
	Lack of suppliers (SC)	3.41	1.15	3.30	3.64	3.39	2.97	3.02*	B > D
	Changes in alternative fuels difficult to predict (TU)	3.48	0.98	3.46	3.45	3.57	3.32	0.56	
	Changes in alternative fuels dependent on many factors (TU)	3.87	0.91	3.85	3.95	3.85	3.71	0.61	
Motivations	*Financially prudent. (C)*	4.11	1.06	3.61	3.91	4.40	4.22	6.10**	A, B < C
	Will give us competitive advantage (C)	3.88	1.14	3.11	3.45	4.28	4.46	19.19***	A, B < C, D
	Will lead to long-term profitability (C)	4.16	1.08	3.41	3.94	4.46	4.43	10.20***	A, B < C, D
	Benefits outweigh costs (C)	3.43	1.16	2.79	3.25	3.79	3.37	7.37***	A, B < C
	We are required to (L)	3.55	1.09	2.93	3.40	3.74	3.85	5.95**	A < C, D
	Will improve firm's image. (L)	3.86	1.08	3.07	3.64	4.09	4.39	11.96***	A < B < C, D
	We feel pressure to. (L)	3.18	1.17	2.86	3.04	3.35	3.31	1.96	
	We need to follow rules and regulations. (L)	3.96	1.11	3.46	3.87	4.07	4.26	3.31*	A < D
	Helping environment is right thing to do. *(En)*	4.24	0.93	3.63	4.16	4.41	4.40	5.96**	A < B, C, D
	Important for us to contribute to better environment. (En)	4.29	0.92	3.86	4.24	4.39	4.49	3.14*	A < C, D
	Helping environment helps us feel good. (En)	3.69	1.12	3.52	3.72	3.85	3.31	2.18	
	Our responsibility to do it. (En)	4.00	1.05	3.39	3.87	4.26	4.09	5.96**	A, B < C, D

Note. 1–5 measurement scale where 1 = full disagreement and 5 = full agreement. Barriers: (Ec) = Economic, (Inf) = Information, (SC) = Supply chain, (TU) = Technological uncertainty. Motivations: (C) = Competitive, (L) = Legitimacy, (En) = Environmental. Tukey's comparisons: A = Laggards, B=Late followers, C = Early followers, D = Early adopters. ****p* < .001, ***p* < .01, **p* < .05.

which lends support to our groupings and the overall findings.

3.2.3. Perceived barriers and motivations

Table 5 outlines ANOVA results on ship-owners' barriers (economic, informational, supply chain, and technological uncertainty) and motivations (legitimation, competitiveness, and environmental responsibility) for adoption of alternative fuels. Laggards see higher barriers than the other groups. Mean (M) scores of the various perceived barrier items generally get progressively smaller going from laggards toward early adopters, who thus see the lowest barriers. There are two items representing information barriers with high and significant F-values, i.e. lack of information ($F = 6.22$, $p < .001$) and lack of knowledge ($F = 9.05, p < .001$),[4] indicating that early adopters perceived these barriers to be lower than other groups. Additionally, there are two barrier items with low but significant F-values, namely, public policy ($F = 3.39, p < .05$) and lack of suppliers ($F = 3.23, p < .05$), showing again that early adopters perceived relatively lower barriers. Apart from these there are no other statistically significant differences between groups on barriers. We can nevertheless note that the highest perceived barrier in all four adopter groups was the economic item of high investment costs ($M = 4.13$).

Regarding motivations, laggards claim the lowest scores of all groups and the mean scores of motivations generally ascend going toward early adopters. Unlike barriers, most motivation items see significant differences between at least two groups. Competitive motivations ("C" motivations in Table 5) stand out, with all four items having relatively large F-values. Early adopters and early followers had higher competitive motivations than late followers and laggards. Among all motivations, competitive advantage has the highest F-value ($F = 17.91$, $p < .001$), while the lowest significant difference is found relative to the legitimacy item covering rules and regulations ($F = 2.70, p < .05$). We also observe that early followers and early adopters have few significant differences between each other and the same can be seen between laggards and late followers. Lastly, the highest overall motivation is the environmental motivation, i.e. that it is important to contribute to a better environment ($M = 4.28$).

The barriers and motivations for alternative fuel adoption seem to differ also between shipping segments. This is suggested by our example comparison between international cargo and coastal fishing ship-owners (the two largest ship-owner segments in our survey). Table 6 shows the means of the responses and a *t*-test results for equality of means. Coastal fishing had significantly lower competitive and legitimacy motivations than international cargo, while there was no significant difference in terms of the environmental motivation. In terms of barriers, coastal fishing reported significantly higher economic and information barriers, however lower technological uncertainty, than international cargo. These results are in line with a higher share of international cargo ship-owners belonging to the early adopter and early follower categories than coastal shipping ship-owners (Fig. 3).

4. Discussion

Our results show that recently a small but distinct group of alternative fuel adopters has emerged among Norwegian ship-owners. Moreover, several others consider adopting alternative fuels in upcoming years. While some ship-owners still express skepticism about alternative fuels and efficiency measures to mitigate climate changes, it is evident that alternative fuel adoption is progressing among Norwegian ship-owners. Our results have thus posed a good starting point to explore how ship-owners differ in such adoption.

A typical storyline in the green innovation literature is that early adopters are new entrant firms, while large incumbents tend to resist change, and act as followers or laggards (Christensen, 2003; Hockerts and Wüstenhagen, 2010). Our results however showed that early adopters were typically large and well-established ship-owners with many (relatively new) vessels, while laggards were mainly young and small ship-owners with few (relatively old) vessels. Some of such differences may be linked to the typical ship-owner characteristics in different shipping segments. For instance, offshore and international cargo ship-owners, which typically included early adopter or early followers, had commonly several vessels which also were relatively new, while for example coastal shipping (often late-followers) had fewer and older vessels.

Tendency of large ship-owners being early adopters and followers may also be linked to the fact that they can more easily experiment with alternative fuels on one or a limited number of vessels. Such experiments in a small share of vessels has only a limited risk for large ship-owners in comparison to smaller ones where experiments would constitute a relatively high share of the ship-owners' overall vessels (perhaps the only one). As Steen et al. (2019) point out, large firms may also have advantages in terms of administrative and technological capabilities when applying for public R&D funding or investment support for piloting in relation to alternative fuels.

While our analysis did not focus on differences between the alternative fuels, some fuels are clearly more feasible in certain shipping segments than in others (see Table 1). For instance, among the early adopters are ship-owners that operate vessels on relatively short and predictable routes, such as within the passenger and offshore supply segments (see Table 2 and Fig. 3). In these two segments public procurement (from Norwegian public authorities at regional and national levels) and contractual requirements (from O&G company Equinor) respectively have driven the uptake of battery-electric systems in recent years (Bach et al., 2020). Whereas some car passenger ferries can operate fully on batteries because of short operational ranges, in the offshore segments batteries are used primarily for 'peak shaving' in hybrid energy systems. Laggards and late followers mainly come from coastal fisheries, which generally do not face external pressure (from customers or in terms of regulations, i.e. licensing system) for adoption of alternative fuels (Bergek et al., 2021).

In international tanker and dry bulk shipping, Poulsen et al. (2021, 2016) found weak cargo-owner demands for emissions abatement and major ship-owner difficulties in relation to environmental upgrading investments beyond energy efficiency. Nevertheless, we now find some Norwegian ship-owners engaged in international cargo shipping among alternative fuel early adopters and early followers. This suggests that a recent change in some international cargo ship-owners' perspectives on alternative fuels may have occurred. It may suggest that the national climate mitigation agenda in Norway spills over also to Norwegian ship-owners who do not operate only on Norwegian waters. Moreover, the Norwegian ship-owners may anticipate changes in demand for low emission shipping in near future, as indicated by the relatively high competitive motivation score for international cargo ship-owners in Table 6.

Our results also pointed to notable differences in adoption behavior within some of the market segments. While for instance offshore and international cargo had rather similar adoption patterns, domestic cargo and domestic passenger segments (see Fig. 3) showed more internal differences. This suggests that some shipping segments may have notable internal similarity in alternative fuel adoption patterns, while ship-owners in some other shipping segments may differ a lot in such behavior.

In sum, then, our results thus suggest that while we can link certain types of structural factors (e.g. shipping segment, size, age, etc.) to occur more likely with certain type of adoption behavior, none of these factors alone seems to explain certain adoption behavior.

We did however find that ship-owners' quest for long-term

[4] 'Lack of information' refers to an experienced lack of publicly available information about new technologies/alternative fuels. Lack of knowledge refers to experienced lack of knowledge within the company about new technologies/alternative fuels.

Table 6
Means and *t*-test for equality of means in motivations and barriers between coastal fishing and international cargo ship-owners.

	Mean		T-test for Equality of Means				
	Int. cargo	Coastal fishing	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
*Competitive motivation****	4.20	3.65	−3.280	111.590	0.001	−0.548	0.167
*Legitimacy motivation****	4.02	3.37	−4.736	131.125	0.000	−0.652	0.138
Environmental motivation	4.28	4.02	−1.767	118.030	0.080	−0.261	0.148
*Economic barriers**	3.73	4.11	2.303	89.041	0.024	0.379	0.164
*Information barriers****	2.97	3.78	4.197	86.789	0.000	0.814	0.194
Supply chain barriers	3.57	3.81	1.236	82.123	0.220	0.241	0.195
*Technological uncertainty barriers**	4.00	3,70	−2.008	89.780	0.048	−0.302	0.150

Note. Mean is measured from a 1–5 scale where 1 = full disagreement and 5 = full agreement. ***$p < .001$, **$p < .01$, *$p < .05$.

profitability, competitive advantage, and improved public image were important motivations for early adopters and early followers. While our survey data does not allow us to explain why, recent studies provide relevant elaborations. Steen et al. (2019) found that some shipping companies no longer see 'business as usual' – characterized by fossil fuels and significant GHG emissions – as viable, and Saether et al. (2021) argued that some Norwegian ship-owners now attempt to secure future market opportunities through adoption of alternative fuels. Stalmokaitė and Hassler (2020) had similar findings. Shipping segment also likely differ in terms of the degree of motivations and barriers, as shown by our example of coastal fishing and international cargo (Table 6).

Our survey data and above-mentioned other studies indeed suggest that the environmental management strategies of major ship-owners may no longer be only dominated by a 'crisis-oriented' approach (van Leeuwen and van Koppen, 2016) and a strong preference for a wait-and-see strategy in relation to alternative fuels (Rojon and Dieperink, 2014). Instead, some major ship-owners are adopting a more proactive approach in alternative fuel adoption, possibly anticipating stronger environmental regulations and/or increasing demand for GHG abatement.

We found environmental regulation to be of relatively low importance for Norwegian ship-owners' adoption of alternative fuels, although early adopters reported higher regulatory motivations than laggards. As the Norwegian government and the Norwegian Shipowners' Association have recently raised the ambition level in reducing the emissions of shipping, we speculate that these results may also point to expectations regarding future regulatory changes.

As far as environmental motivations for alternative fuel adoption are concerned, we found that this type of driver was strongest among early adopters and early followers, but they also seemed to matter for late followers and laggards. Thus, environmental motivations and awareness about climate change alone do not seem to be enough to motivate shipowners to adopt alternative fuels.

Unsurprisingly, all ship-owners in our sample found high investment cost and financing difficulties as major barriers for alternative fuel adoption, but early adopters could more easily overcome them. Moreover, early adopters seemed to possess more knowledge about alternative fuels. These findings suggest that the ship-owners' resources (e.g., knowledge, finances, and vessels) may affect the likelihood of adoption of alternative fuels, and this topic merits further research attention.

5. Conclusion and policy implications

In a survey of Norwegian ship-owners' adoption of alternative fuels, large and old offshore, international cargo, and passenger ship-owners with relatively new fleets stand out as early adopters. In contrast, small and young firms with old fleets, especially within coastal fisheries were generally laggards or late adopters. Awareness about environmental issues is generally high among Norwegian ship-owners, but such considerations alone have not driven the option of alternative fuels. Instead, many early adopters were subjected to emission reduction requirements by their Norwegian public and private customers (particularly visible in offshore supply), whereas such pressures were largely absent for laggards in for instance coastal fisheries. For the relatively small group of early adopters as well as early followers, quest for long-term profitability, competitive advantage, and improved public image were important motivations for adoption of alternative fuels.

In this final section of this exploratory paper, we reflect upon the policy implications of this study, its limitations as well opportunities for further research.

5.1. Policy implications

In identifying the main characteristics of alternative fuel early adopters and laggards in Norway, our study has implications for national as well as international policymakers.

Norwegian policymakers should be particularly aware of the small and new companies, such as in coastal fisheries, which do not intend to adopt alternative fuels. These companies do not seem to have resources to experiment with alternative fuels or apply for public R&D funding for such ventures, and they do not experience any strong market pressures to do so. Our results thus suggest that while the conditions for alternative fuel adoption have been somewhat conducive in Norway for large and established ship-owners, smaller companies in general have been less able to follow suit. Hence, companies with limited in-house resources and capabilities may require additional support through financing and competence building opportunities. Moreover, Norwegian as well as other national policymakers may consider designing R&D support programs specifically for such shipping companies, and possibly include GHG abatement as a decision criterion when granting for example fishing or aquaculture licenses.

Our results suggest that market-pull mechanisms rolled out by both public and private actors may be effective in driving alternative fuel adoption. Many early adopter firms were from market segments which had been subjected to emission reduction requirements in contracting mechanisms, such as passenger vessels and offshore supply vessels, the former governed by publicly owned organizations and the latter by customers (i.e. petroleum companies) with strong incentives to reduce GHG emissions. While similar governance mechanisms may not be applicable in all market segments, early adoption in some segments may create important niche markets for alternative fuels. This can create momentum for key innovation processes such as experimentation, more sophisticated demand articulation and learning around alternative fuels (cf. Bach et al., 2020). These processes are likely to result in cost reductions, building of infrastructure, diminishing technological uncertainty and knowledge building, thus reducing barriers for broader adoption. Active market creating governance by national policymakers, for instance through public procurement of shipping routes, may thus be a crucial policy mechanism in stimulating the emergence of early niche markets for alternative fuels in shipping.

Our results also show that even in a front-runner country like Norway, alternative fuel adoption in shipping is yet in an early phase. It is therefore still necessary to support alternative fuel innovations with technology push mechanisms, such as with R&D funding. Battery-electric technology appears to have momentum and is most widely adopted, but it should be noted that batteries are unlikely to generate major GHG emission reductions in shipping globally. In our survey, alternative fuels such as ammonia and hydrogen that have higher potential for emission reductions (due to their applicability in vessels with longer operational distances) were seen as solutions for the more distant future. For the global shipping sector to mitigate its emissions, R&D support for further development of such fuels is crucial, including new infrastructure and other complementary technologies.

On an international scale, policy makers should consider how market pull mechanisms can help incentivize the adoption of alternative fuels. In international cargo shipping, governments are not the main customers, and they can only use their procurement policies to incentivize alternative fuel adoption to a limited extent. It is therefore important that they support the development of market pull mechanisms, which can cause key shipping customers (e.g. oil majors, commodity traders and major consumer goods companies) to demand emissions reductions from ship-owners.

5.2. Limitations and future studies

Our findings have provided some of the first systematic insights on ship-owners' adoption of alternative fuels in a frontrunner country. The results should be of interest and relevance also beyond the Norwegian context. However, our study is not without limitations.

First, we define early adopters as any ship-owners who have adopted at least one alternative fuel onboard one vessel. Thus, we do not distinguish between ship-owners who have equipped only one ship with a battery-storage system for 'peak-shaving' from ship-owners with more comprehensive decarbonization initiatives in their entire fleet. However, as the adoption of alternative fuels in shipping is yet a marginal phenomenon, we believe our operationalization of adoption to be valid.

Second, we did not analyze how the preferred alternative fuels may have affected the perceived motivations and barriers. This can be relevant as some more mature technologies, like battery-electric, may not be applicable in some shipping segments. Responses may therefore be affected by a perceived lack of available alternative fuels both now and in coming years. The connection between the availability of alternative fuel solutions in different shipping segments and ship-owners' attitudes and expectations to adoption thus remains an important topic for future studies.

Third, our study concerned ship-owners in Norway, which is a center for maritime technology development and has a government with more ambitious GHG abatement goals than the IMO. We suggest that further studies should study alternative fuel adoption in other major ship-owner countries, to explore how national contexts may affect ship-owners' decarbonization efforts.

Fourth, as some shipping segments had only limited respondents in our survey, we could not perform a systematic quantitative analysis between adoption differences between several different types of shipping. Because previous qualitative research both on coastal (Bergek et al., 2021) and deep-sea (Poulsen et al., 2018) shipping suggests that segment-specific factors may have strong influence on adoption of alternative fuels, future quantitative studies should aim to further investigate differences in adoption behavior between different shipping segments.

Finally, our research has had little attention to exploring differences in adoption behavior within a single market segment. Investigations on why ship-owners differ in terms of alternative fuel adoption from their competitors would help to further shed light on explanations behind alternative fuel adoption.

CRediT authorship contribution statement

Tuukka Mäkitie: Conceptualization, Investigation, Visualization, Writing – original draft. **Markus Steen:** Conceptualization, Investigation, Funding acquisition, Project administration, Writing – original draft. **Erik Andreas Saether:** Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Øyvind Bjørgum:** Conceptualization, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **René T. Poulsen:** Conceptualization, Writing – review & editing.

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.

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Appendix

Table A1
Survey measures

Variable/construct	Response question, scale, and items
Firm age (year of establishment)	In what year was your firm established? **1** = 2015–2019, **2** = 2010–2014, **3** = 2000–2009, **4** = 1980–1999, **5** = 1950–1979, **6** = 1900–1949, **7** = before 1900
Nr. of employees	How many employees does your firm have? **1** = 1–2, **2** = 3–5, **3** = 6–9, **4** = 10–19, **5** = 20–49, **6** = 50–249, **7** = 250 or more
Nr. of vessels	How many vessels does your firm own? **1** = 1, **2** = 2–3, **3** = 4–5, **4** = 6–10, **5** = 11–20, **6** = 21–30, **7** = 31 or more
Age of vessels (in years)	On average, how old are your vessels? **1** = 0–5, **2** = 6–10, **3** = 11–15, **4** = 16–20, **5** = 21–30, **6** = 31–40, **7** = 41 or more
Segment *(D) = domestic* *(I) = international*	What segment does your firm primarily belong to? (choose one) *ocean fishing (I); coastal fishing (D); international cargo (I); domestic cargo (D); international passenger (I); domestic passenger (including car ferry) (D); offshore supply and services (I); ship lessors (I); tug services (D); other*
Alternative fuel adoption	When do you expect your firm to adopt the following technology/fuels on at least one of your vessels? **1** = will never adopt, **2** = over 20 years, **3** = within 20 years, **4** = within 10 years, **5** = within 5 years, **6** = within 2 years, **7** = already adopted *Electric; LNG; Biodiesel; Biogas; Hydrogen; Ammonia; Methanol*
Green modifications adoption	When do you expect your firm to adopt the following modifications, maintenance, or operations on at least one of your vessels? **1** = will never adopt, **2** = over 20 years, **3** = within 20 years, **4** = within 10 years, **5** = within 5 years, **6** = within 2 years, **7** = already adopted

(*continued on next page*)

Table A1 (*continued*)

Variable/construct	Response question, scale, and items
	Design modifications to reduce drag (e.g. rotor sails, streamlined hull, lighter materials, aerodynamic improvements, propellers with fins, copper hull, etc.); Design modifications for cleaner or reduced emissions (e.g. scrubber, carbon capture, etc.); Environmentally friendly maintenance (e.g. polarizing propellers, cleaning ships to reduce drag, etc.); Environmentally friendly operations (e.g. sailing slower, using more efficient routes, etc.)
Barriers	My firm is hindered from adopting emission-reducing technology/fuels because…
(Ec) = Economic,	**1** = completely disagree, **2** = slightly disagree, **3** = neither disagree nor agree, **4** = slightly agree, **5** = completely agree
(Inf) = Information	*… of high investment costs. (Ec)*
(SC) = Supply chain	*… it is difficult to finance. (Ec)*
(TU) = Technological uncertainty	*… there is insufficient support from public policy. (Ec)*
	… there is a lack of information on ECs. (Inf)
	… we lack knowledge on ECs. (Inf)
	… there is a lack of infrastructure. (SC)
	… there is a lack of suppliers. (SC)
	… changes in ECs are difficult to predict. (TU)
	… changes in ECs are dependent on many factors. (TU)
Motivations	My firm is interested in adopting emission-reducing technology/fuels because…
(C) = Competitive,	**1** = completely disagree, **2** = slightly disagree, **3** = neither disagree nor agree, **4** = slightly agree, **5** = completely agree
(L) = Legitimacy,	*… it is financially prudent. (C)*
(En) = Environmental	*… it will give us competitive advantage. (C)*
	… it will lead to long-term profitability. (C)
	… the benefits outweigh the costs. (C)
	… we are required to. (L)
	… it will improve our firm's image. (L)
	… we feel pressure to. (L)
	… we need to follow rules and regulations. (L)
	… helping the environment is the right thing to do. (En)
	… it is important for us to contribute to a better environment. (En)
	… helping the environment helps us feel good. (En)
	… it is our responsibility to do it. (En)

Table A2
Median groups of respondent characteristics in different shipping segments (see the different groupings for all responses in Appendix, Table A1)

	Year of establishment	Number of employees	Number of vessels	Vessel age
Ocean fishing	1950–1979	20–49	1	11–15 years
Coastal fishing	2000–2009	3–5	1	16–20 years
Aquaculture	2000–2009	20–49	4–5	6–10 years
Domestic passenger	2000–2009	6–9	4–5	21–30 years
Domestic cargo	2000–2009	10–19	2–3	31–40 years
International cargo	1980–1999	20–49	11–20	11–15 years
Offshore supply	2000–2009	250 or more	11–20	11–15 years
Other	2000–2009	3–5	2–3	11–15 years

Table A3
Alternative fuel adoption groups and respective shipping segments

	Laggards	*Late followers*	*Early followers*	*Early adopters*	Total
Ocean fishing	1	13	11	2 (1 electric; 1 biodiesel)	27
Coastal fishing	20	52	27	4 (3 electric; 1 biodiesel)	103
Aquaculture	2	4	14	3 (1 electric; 2 biodiesel)	23
Domestic passenger (including ferries)	2	7	12	5 (4 electric; 2 LNG; 3 biodiesel)	26
International passenger	0	1	1	2 (1 electric; 1 LNG; 1 biodiesel)	4
Domestic cargo	2	5	2	3 (3 LNG)	12
International cargo	4	8	30	8 (3 electric; 5 LNG; 2 biodiesel)	50
Offshore supply and services	1	1	3	10 (9 electric; 6 LNG)	15
Ship lessors	3	4	6	1 (1 LNG)	14
Tug services	2	2	2	1 (1 LNG)	7
Total	37	97	108	39	281

Note. Alternative fuels in parentheses are used to denote those already adopted.

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