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Marine energy transition with LNG and electric batteries: a technological adoption analysis of Norwegian ferries

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Abstract

Purpose – The article investigates factors associated with the relative success in adopting two specific alternative marine energies (liquefied natural gas [LNG] and electric batteries) in the Norwegian ferry market. This specific market segment is an interesting case study as its national-flagged fleet boasting the largest number of ships using alternative marine energies in comparison with the other countries of the region and the world.

Design/methodology/approach – A database tracking the yearly deployment of ships using a different combination of LNG and electric batteries was built from shipping lines' online information and grey literature. The technological adoption approach was used to categorize different groups of users at each step of the adoption process and identify which factors separate the early adopters from the other groups of end-users. The compiled data allow tracing the changing distribution of Norwegian ferry operators along the conceptualized technology adoption curve.

Findings – Results indicated that the Norwegian ferry market matches required conditions to pass the "chasm" of uncertainties associated with transitioning to new technology. Some disparities between the adoption of LNG and the electric batteries in the Norwegian ferry markets are observed.

Originality/value – To the authors' knowledge, no study has explored the adoption of new energies in the maritime industry based on the technology adoption process through a similar perspective. The analysis is helpful to shed light on the barriers associated with a high level of uncertainties when it comes to adopting new marine energies.

Keywords Energy transition, Alternative marine energies, Technological adoption approach, Early-adopters, Norway ferries

Paper type Research paper

1. Introduction

Shipping is an enormous contributor to worldwide transport markets. Over 80% of world trade by volume is carried by ships (Hoffman and Sirimanne, 2017). About 3% of global greenhouse gas emissions are attributed to this activity (Smith *et al.*, 2015). The sector is also a significant contributor to air pollution in coastal and port areas (Rata and Rusu, 2019; Viana *et al.*, 2014). The adoption of alternatives to fossil fuel energies by the shipping industry would provide a significant tool to cut atmospheric emission and meet climate change policies' targets. Despite their attractiveness in terms of energy efficiency and environmental solution, the alternative marine energies are still not widely used within the world fleet (MIDC, 2020), which continue to rely primarily on bunker fuel and marine diesel. However, some progresses are reported in specific market segments defined by specific ship types and/ or routes or propulsion technologies. The adoption of liquefied natural gas (LNG) and electric batteries in the Norwegian ferry market suggests a promising change (Bach *et al.*, 2021; Smith *et al.*, 2015): Norway has even been qualified by some observers as a worldwide laboratory of

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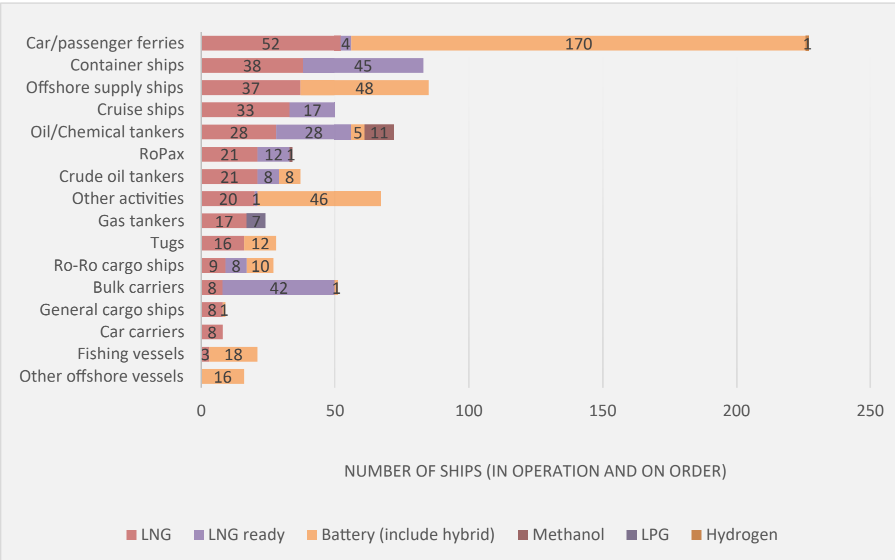
alternative marine energies (DNV-GL, 2019). What factors explain that the adoption of the alternative marine energies is further advanced in the Norwegian ferry market? To answer this question, the authors opted for technology adoption perspective: first to look for factors explaining the success story of early adopters of alternative marine energies and second to shed light on the barriers created by high levels of risks and uncertainties when adopting new propulsion technology. In the context of this paper, the authors will use the terms alternative energy instead of alternative fuel, given that electricity (via batteries) is not technically a fuel. The article is structured as follows. The first section will describe the general context of alternative marine energies in the Norwegian ferry segment. The second section will be present frameworks used in the literature to conceptualize the adoption of new energy technology. The third section will be devoted to the methodology and the material used in this study. The final section of the paper will present the key findings.

2. Norway as a leader in the adoption of alternative marine energies

Commonly recognized alternative marine energies include LNG, liquefied propane gas (LPG), electric batteries, hydrogen, biofuels, methanol, dimethyl ether (DME) and ammoniac (IMO, 2020). Other alternative energies could also be considered, such as solar, wind, nuclear, hydropower and biomass, but for now, these energies are still restricted to experimental projects (Li, 2017). Among the mentioned alternative energies, LNG, LPG, methanol, biofuel, hydrogen and electric batteries seem to be the most promising solutions (EAFO, 2019). According to DNV-GL (2019), LNG and electric batteries are currently the most frequently deployed alternative propulsion mode across the world fleet (Figure 1). In terms of ship-type, car and passenger ferries are the category with the higher number of ships using alternative marine energies worldwide.

Within the early adopter, Norway seemingly played a crucial role by introducing the first ferries powered with alternative energies. Indeed, three of the most promising alternative



Source(s): Alternative Fuels in the World Fleet (Update July, 2019)(DNV-GL, 2019)

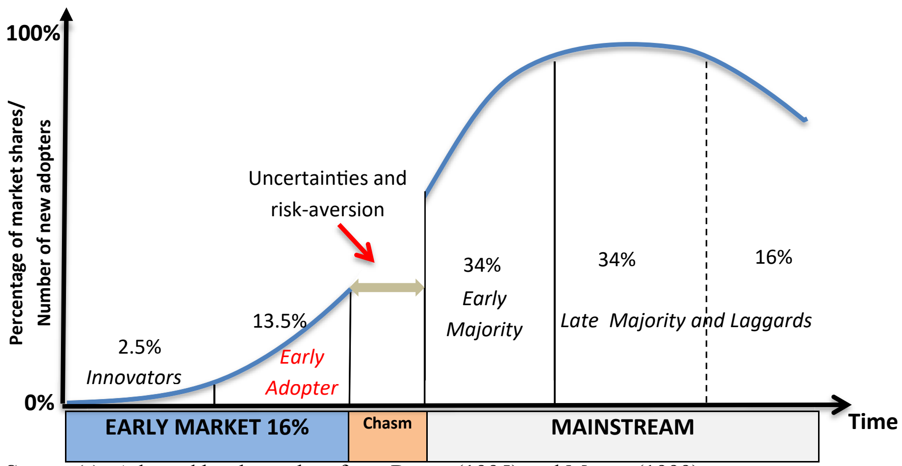
Figure 1.
World's fleet using alternative energies

energies to fossil fuels have already been deployed aboard Norwegian-flagged ferries: LNG, electric battery and hydrogen (DNV-GL, 2019). Regarding LNG, the MF Glutra (the name of this vessel) was the world's first LNG-fueled car and passenger ferry operated by the Norwegian company Fjord Line. The company started operating MF Glutra in Møre og Romsdal County in 2000 (Le Fevre, 2018). Following MF Glutra, several Norwegian ferries and offshore service vessels adopted LNG as fuel. The niche accumulation process then spreaded to other different ship types and shipping segments. Thus, the past years have seen the first icebreaker, bulk carriers, car carriers, container ships, roll-on, roll-off (Ro-Ro) cargo ships, oil/chemical tankers, and dredgers and cruise ships using LNG (Laribi and Guy, 2020). It took 13 years for LNG fuel to spread outside Norwegian fleet (DNV-GL, 2018). The first fully electric car and passenger ferry, MF Ampère, has been in service between Lavik and Oppedal on the west coast of Norway since 2015. The interest in electric ferries has considerably grown in Europe since this initial project. The fully electric concept aims to become a game-changing approach to short- and medium-range ferry connections (Gagatsi *et al.*, 2016). Limited shore-based infrastructure for charging is available today, but progress is made in specific regions (Government of Norway, 2019).

3. Technology adoption lifecycle applied to alternative marine energies

3.1 Innovators versus early adopters in the Norwegian Ferry segment: a thin line

The adoption of new technology (or new energy) across a group of end-users is thought to follow a normally distributed "bell curve" pattern (Moore, 1991; Rogers, 1995; Christensen, 1997). Rogers (1995) separates the Technology Adoption Lifecycle into five end-user categories spread over this bell curve (see below Figure 2). Literature on the adoption of technology typically classified all end-users into several subgroups based on their adoption timing: *innovators, early adopters, early majority, late majority* and *laggards* (Bass, 1969; Rogers, 1995). Rogers (1995) attributes a percentage of market shares to each end-users group as an indication part, albeit these percentages could vary from a market to another. Mahajan *et al.* (2000) prefer using the number of new adopters instead of market shares. The number of new adopters can also be turned into either a percentage compared to the total of potential new adopters or cumulative adopters (Mansfield, 1961). The innovators, the first group, are not as concerned



Source(s): Adapted by the authorsfrom Roger (1995) and Moore (1999).

Figure 2.
Technology
adoption curve

with monetary returns as they are with the innovation potential. The innovators want to experiment with the new technology as soon as possible to learn its potential. They represent a tiny percentage of the market (generally from 0 to 2.5% of the market). The early adopters, the second group, have a positive attitude toward innovations and are comfortable taking risks but are primarily motivated by potential opportunities to grow their business. These end-users see value for the new technology within their industry before their competitors (Frattini *et al.*, 2014). They are willing to risk technical immaturity, recognizing that not all aspects of the new technology have yet been worked out. They represent the part from 2.5 to 13.5% of the market. These first two segments together – the innovators and the early adopters – are referred to as the early market (Moore, 1999). Early majority members, the third group, will adopt the innovations only after they have been market proven and feel comfortable that it will not put them at risk. They are the largest segment of the market (generally from 13.5 to 34% of the whole). These end-users are receptive to new technology, but they are more conservative and risk-averse than the two first groups. This group does not want to commit to an untested technology that may have imperfections reducing its efficiency or efficacy, or that is not the technology the competitive market will embrace (Moore, 1999). The final groups, the late majority group and the laggard group, are conservatives. The late majority group comprises users who are much more risk-averse and extremely cautious when using any new technology. They will not commit to a new technology until certain technological and economic uncertainties have been resolved; they will wait until it is professionally uncomfortable in their industry to remain loyal to the old technology (Moore, 1999). The final group is formed by members who will strongly resist the new technology and use it only if forced to. Together, they typically form about half of the market.

In the case of the ferry segment using alternative marine energies, the frontier is fragile between the innovators and the early adopters. Norwegian Ferry companies such as Fjord 1 or Norled AS are involved in the innovation process along various partners (such as vessel designers, system suppliers or environmental researcher) to develop and/or adapt new alternative propulsion mode for ships and then can become the first to adopt the new energy technologies onboard their ferries. Fjord 1 worked with different partners, including Rolls-Royce Marine, Caterpillar, Mitsubishi and AKER Langsten AS, to launch the world's first LNG-fueled ferry: MF Glutra. The impact, on the whole, is more efficient when these companies are leaders in their market segments, a role usually attributed to the early adopters. Indeed, Fjord1 is the leading operator within Norwegian ferry operations with a market share of approximately 50% in 2018 (measured by the number of private car units transported) (Fjord 1 Annual Report, 2018). Other companies followed a similar path in the adoption of alternative marine energies. For instance, the world's first all-electric ferry MF Ampere was the result of a partnership between Norled AS (the ship-owner and the carrier) and two innovation leaders in the electric industry, namely Corvus Energy and Siemens AS. Corvus Energy provides high power modular lithium-ion battery systems for hybrid and fully electric heavy industrial equipment, and large marine propulsion systems. The company has a recognized expertise in using battery technology aboard ships to reduce emissions claiming the highest number of installations worldwide (Corvus Energy, 2021). Widely known Siemens AS is a worldwide leader in electric systems and also a developer of electric propulsion systems (Siemens, 2021).

3.2 Barriers to alternative marine energies adoption: uncertainty and risks

The pictorial representation of the technology adoption curve (see Figure 2) is closely related to the *product lifecycle* curve (Mercer, 1993), where the first phases of the lifecycle are determinant to the market success of a product. The success of the adoption of technology is crucially related to the first half of the adoption curve. Whereas Rogers (1995) sees continuity in the technology adoption process between the distinctive adopter groups, Moore (1991, 1999) sees an apparent discontinuity in the process. Some other authors characterize this discontinuity as a saddle (Chandrasekaran and Tellis, 2011): in other words, a momentary inflection in the level of adoption. However, some researchers have questioned this notion pointing to the critical transition between the early adopters and the early majority (Goldenberg *et al.*, 2002; Van den Bulte and Joshi, 2007) because the diffusion process can be just filled by targeting the innovators and the early majority (Mahajan and Muller, 1998; Rogers, 1995). Moore (1991, 1999) suggests that "cracks in the bell curve" may exist between groups of adopters. According to Moore, the most significant crack separates the early adopters from the early majority: this chasm can represent a significant adoption barrier preventing the new technology to take-off. Yet, continuity does not mean that no chasm can occur but may mean that sufficient favorable conditions allow the adopters to cross the threshold (Rycroft, 2006). The chasm reflects the significant barriers confronted as technologies advance from the early adopters to early majority phases. These barriers encompass all the situations that could increase uncertainties and risks in adopting the new technology. Indeed, the risks and uncertainties are common features of every innovative project (Park and Yoon, 2005), and all new energy adoption projects also involve uncertainties. There can be uncertainties about the performance, impacts and future relevance of different new (and old) energy technologies. There are always uncertainties about policy and market development (Rosenberg, 1996), which can influence the performance of different emerging energy technologies (Heiskanen *et al.*, 2008). Uncertainty starts to decrease in the perception of potential adopters as the adoption rates reach a certain level (16% of the total potential adopters in Rogers's model (1995)). Cialdini and Rhoads (2001) have also proposed the 16% threshold to pass from the early market to the mainstream market and suggested it is linked to social influence affecting the potential adopters' perception of the risks involved with the new technology.

Alternative marine energies induce a wide range of risks and uncertainties which are twofold. First, they are typical technical and business uncertainties related to all alternative or new marine energies. At the early stage, the market size for new energies is minimal, and the innovation prices are too high for customers to adopt these energies under conditions of technological and market uncertainty (Rosenberg, 1996). For example, in the case of energy efficiency, the financial impact of the investment depends on the future price (Heiskanen *et al.*, 2008). Second, the societal uncertainty related to the energies transition in the maritime industry toward more sustainable energies (Elzen *et al.*, 2004). Many authors have widely discussed the role of deep uncertainty in transitioning from one consumption "regime" to another (Geels, 2012; Lyons and Davidson, 2016). Beyond the consumption changes involved, the transition from fossil fuels (such as marine diesel or heavy fuel) to low (e.g. LNG) and zero (e.g. electric battery) emission energies implies a fundamental paradigm shift in the maritime industry (Monios and Wilmsmeier, 2020). In such circumstances, policymakers are often risk-averse and locked into the incumbent policy regime (Roberts and Geels, 2019). They can reposition in to promote greater use of alternative energies only under certain political conditions, such as shifts in public opinion or by promoting these new energies through different instruments or pilot projects (Jordan-Korte, 2011). In this regard, ferries form a part of the public commuting systems of many coastal cities and islands. Public support is typically needed in this sector to first guarantee the continuity of services and, second, services' responsive adaptation to increasing social and environmental expectations. Such support could take the form of funds that reward early adopters (Hendry *et al.*, 2010) to benefit from allocating sufficient funds to innovate. Without government support, early adopters are disadvantaged by paying and taking the risk without any rewards (Catalini and Tucker, 2017) while others wait to reduce cost and investment uncertainty before investing in the technology (Locatelli *et al.*, 2016). Governments can support financially part of the extra operating costs faced by early-adopters, mainly one-off costs like the re-training of the workforce participating in the pilot projects? Regarding safety and handling zero-emission fuels (Energy Transitions Commission, 2020). Differences in policy approaches are also rooted in cultural differences, different geographical conditions or different institutional factors (Heiskanen *et al.*, 2008). Many studies also found that social and cultural characteristics impact the diffusion of innovations and technologies (Tellis *et al.*, 2003). For instance, in Scandinavian countries, solid environmental awareness exists that can influence the importance of environmental arguments in the project's vision and expectations. Environmental benefits, especially climate change mitigation, can be essential arguments in countries with a longstanding tradition of environmental awareness but may be less essential arguments elsewhere (Heiskanen *et al.*, 2008).

Therefore, to assure continuity in adopting alternative marine energies, there should be adequate technical, economic, geographical and political conditions to minimize perceived risks for the maritime suppliers and ship operators. Given that the ferry market segment accounts for the higher number of ships using alternative marine energies in the Norwegian fleet, one can question if the segment matches all the conditions required to pass Moore's (1991, 1999) chasm of uncertainty?

4. Method and material

We have chosen to embrace the technology adoption approach, which scrutinizes the adoption process through the number of new adopters and stresses the barriers that may impede the new technology adoption process: investment uncertainties, market/business uncertainties and technical uncertainties. We have opted for this approach due to its originality and seemingly good fit for our case study. To our knowledge, no study analyzes the adoption of alternative marine energies through this lens. Our study documents the use the two principal alternative marine energies (LNG and electric batteries) in the ferry segment in Norway. Fleet information has been divided into two categories. The ferries using LNG including dual-fuel (LNG with diesel), and the ferries using electric batteries including hybrids (electric with propulsion from LNG or diesel generator).

We have paid particular attention to the ferry segment because it has many ships using alternative energies worldwide: shorter shipping routes with repetitive designated ports of call are indeed facilitating conditions to deploy new propulsion technologies. Furthermore, we have chosen to investigate the situation in Norway because it is the ship register where the greater number of ferries using alternative energies are recorded. In the present study, the authors refer to the ferry as a form of transportation using a ship to carry passengers and sometimes vehicles across a body of water (rivers, lakes and seas) and operating on regular, frequent return services. We have included all types of ferries carrying passengers and vehicles: High-speed ferries (or Catamarans), Ro-Ro ferries, Ro-pax ferries and Double-ended ferries. However, only ferries in operation were counted; therefore, ferries in order in shipyards or ferries stopped for reparation were not considered in the study. Moreover, only ferries that are operating under the Norwegian flag are counted. The covered period is from 2000 (the year of the first Norwegian electric ferry) to October 2021 (when the study has been released). Thus, all figures and tables presented in the next section are about this period.

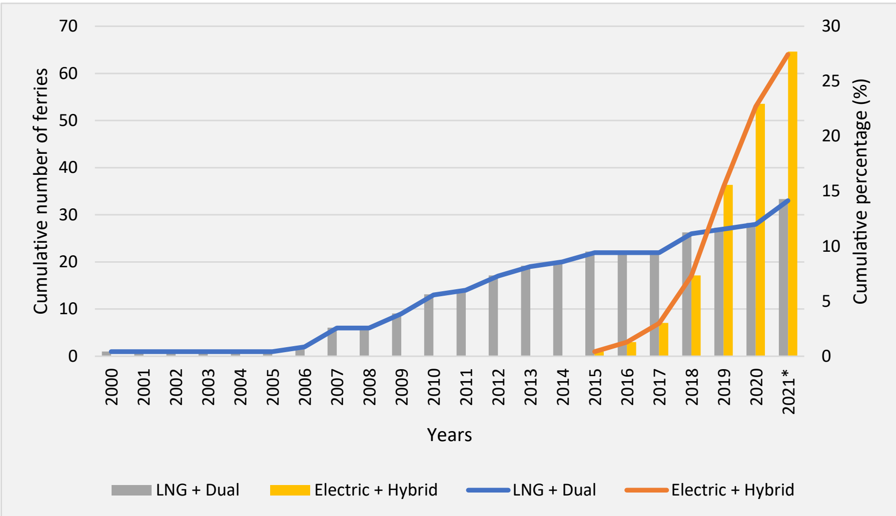
Data were collected on-line from (1) publicly available information provided by the Norwegian Maritime Authority or the Norwegian Coastal Administration and (2) dedicated websites monitoring the ferry industry (The Ferry Site) or offering ship tracking services (Marinetraffic.com and Vesselfinder.com). Finally, remaining gaps in information were supplemented through reviewing individual company reports and academic literature. The collected information has been cross-checked and validated between the different sources.

5. Findings and discussion

5.1 Passing the early market stage in LNG and hybrid ferries segment

As illustrated in Figure 3, both alternative energies curves (LNG and electric) are on a growing trend during the period studied. Although electric ferries first appear only in 2015, their current cumulative number (64 ferries) is nearly double that of LNG and dual-fuel (DF) ferries (33 ferries). In other words, the electric and hybrid ferries have deployed increasingly rapidly in a short period (2015–2021) compared to LNG and dual-fueled ferries (2000–2021). That indication could suggest a high level of confidence and a lower risk aversion to the alternative energies from the ship-owners. The forecast for 2021 confirms this tendency. Sixty-four are fully electric or hybrid, representing about 27.7% of the potential users (the current 231 accounted Norwegian-flagged ferry are used for the purpose of our analysis as the whole potential users). This adoption level demonstrates that the electric and hybrid ferries segment has passed the chasm and has reached the mainstream market stage. The LNG and dual-fueled ferries have shown a slower increase, especially from 2015 when electric and hybrid ferries enter the market. Of the current total Norwegian ferry fleet, 33 are full LNG or dual-fueled ferries, representing about 14.3% of the potential users. This adoption level shows that the LNG and dual-fueled ferries segments have not passed the chasm yet. It could be assumed that this ferries segment is at a critical stage of the adoption process because some doubts persist about its adoption. Such a situation can occur when end-users are uncertain about the future or when some signals coming from government programs or from international maritime regulations that their support for the technology may lessen. It could be the case since the LNG does not fit entirely with the Norwegian government's zero-emission targets. It is worth noting that the scissors shape of the two curves could also reveal that these two alternative marine energies compete, where one or both are more suitable with the ferry market and therefore more attractive to ship-owners. However, we argue it is still too soon to confirm it.

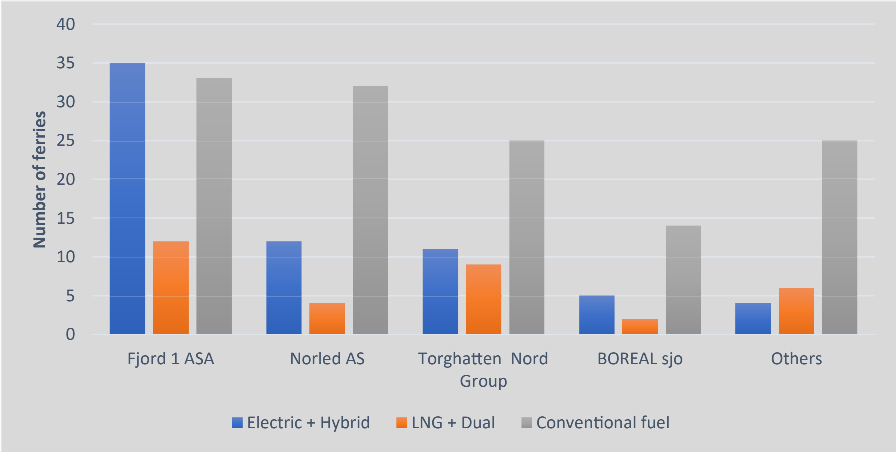
Figure 4 suggests the same level of interest in electric and hybrid ferries when observing the distribution of energy choice among individual companies' fleets. The most important



(*) figures till October, 2021.

Source(s): Norwegian Maritime Authority (2021), Norwegian Coastal Administration (2021) and Ferry-site.dk (2021)

Figure 3. Cumulative number and percentage of LNG-fueled and electric-powered ferries



(*) figures till October, 2021.

Source(s): Norwegian Maritime Authority (2021), Norwegian Coastal Administration (2021) and Ferry-site.dk (2021)

Figure 4. Distribution of LNG-fueled and electric-powered ferries by company (2000–2021*)

companies in terms of numbers of ships deploy have the most significant number of electric and hybrid ferries. For LNG-fueled ferries, the innovator companies are also the early adopters of the technology. A company such as Fjord1 launched the first LNG-fueled ferry on the market in 2000 and continued to launch new or converted LNG-fueled ferries during the following years. Following this initial market entry, Norled AS in 2009 and Torghatten Nord AS in 2012 putted in service LNG-fueled ferries. Both companies are considered early adopters, and they continue to increase their fleet in LNG-fueled or dual-fueled ferries since their entry into the alternative energies segment. The case of the electric-powered ferries appears different given the diversity of companies playing active roles in the very early stage of the market. The Norwegian company Norled AS launched the first all-electric passenger and car ferry in 2015 and became an innovator and early adopter of electric-powered ferries in Scandinavia. Two years later, the companies Torghatten and Fjord 1 ASA joined the market with their first electric ferries.

Going back to the conceptual models of transitions, is our time series shown in Figure 4 sufficient to suggest that alternative propulsion technologies have reached and passed the threshold discussed in the literature (Rycroft, 2006; Cialdini and Rhoads, 2001). Since the Norwegian ferry market is a specialized niche within the shipping industry, we argue that it is too early to conclude that we entered the generalization phase beyond the threshold but that change is visible and worthy of attention. Hence in the following sections, we move from a times series perspective to focus on drawing a more detailed picture of the current situation.

5.2 Investments uncertainties: strong support from the public

Public support mechanisms such as direct grants dedicated explicitly to “early adopters” entering the low- and zero-emission marine fuel market can reduce investment requirements at a crucial step of the market introduction. Table 1 shows some of the main programs implemented at the European and Norwegian levels to support maritime companies investing in alternative energies. As a member of the European Economic Area (EEA), Norway can benefit from European Union supports through agencies like the Innovation and Networks

	Institutions/ agency	Program/project	Objectives	Alternative energy	Example of vessels or projects funded
European Commission	Innovation and Networks Executive Agency (INEA)	Horizon 2020	The program provides funding the innovation process, from basic research to market uptake, and targets explicitly significant societal challenges such as health, energy and transport	Hydrogen LNG	MF Hydra (2020) Under construction (2022)
		Geographical Islands Flexibility (GIFT)	The project aims to decarbonize the energy mix of European islands by developing and installing innovative systems that increase the share of renewable energy sources	Electric batteries	e-Ferry (ongoing project)
Norway	Norwegian Ministry of Climate and Environment	NOx Fund (I and II)	All ships operating in Norway pay into the fund. Shipping companies can then apply for a subsidy from the same fund to finance projects that would help to reduce NOx emissions from their ships	LNG Electric batteries	MF Boknafjord (2011) MF Ampere (2015)
		ENOVA	Developing an energy and climate plan to processes for a municipality to achieve its energy efficiency, renewable energy and reduction of greenhouse gas emissions	Electric batteries Hydrogen	Future of the Fjords (2018) Rygerelektra (2021) HIDDLE (under construction)
	Norwegian Directorate of Public Roads		Responsible for the state and county public roads in the country, including planning, construction, and operation of the state and county road networks, driver training and licensing and subsidies to car ferries	LNG	MF Glutra (2000)

Source(s): Compiled by the authors

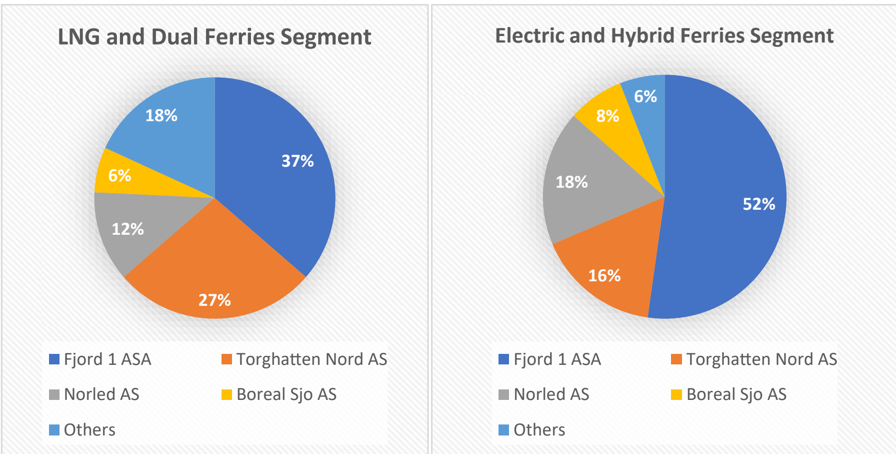
Table 1.
European and Norwegian programs aiming to support ferry projects using alternative energies

Executive Agency (INEA) or the Trans-European Transport Networks (TEN-T). In addition, at the national level, government authorities such as the Norwegian Ministry of Climate and Environment or the Norwegian Directorate of Public Roads add to the EU initiatives. Two national initiatives have had success in Norway: the Nox Fund and ENOVA. The Nox Fund I

(2007–2017) and II (2018–2025) are an environmental agreement between 15 Norwegian business organizations and the Norwegian Ministry of Climate and the Environment. Under this agreement, affiliated enterprises are exempt from the Nox tax and pay into the Nox Fund. The NOx tax targets solely domestic ships. The Fund is used to provide financial support for Nox reduction measures by affiliated enterprises paid into the Fund. This support covers additional costs of Nox reduction measures, such as engine modifications in ships, the use of LNG plus batteries, or installation of selective catalytic reduction (SCR) technologies.

5.3 Market and business uncertainties: high concentration and short routes

Figure 5 illustrates the high level of concentration among the alternative energies (LNG and electric) ferry market segment. The market segment is shared between a few companies, and three of them (Fjord1, Norled AS and Torghatten Nord AS) account for over three-quarters of the fleet deployed. In the case of the Norwegian ferries market, early adopters have a strong experience and a long tradition within the industry. Fjord1 is the leading operator within Norwegian ferry operations, with a market share of approximately 50% in 2018 (in terms by the number of private cars transported), and operates seven of the ten ferry connections in Norway with the highest traffic volumes (Fjord1 Annual Report, 2018). Fjord1 was formed in 2001 by the merger of two of the oldest Norwegian ferry companies Møre og Romsdal Fylkesbåtar (founded in 1920) and Fylkesbaatane i Sogn og Fjordane (founded in 1858). This leading position is maintained in the alternative energies ferry market, where the company holds 37% of the LNG-fueled ferries and 52% of the electric-powered ferries. The following two companies, Torghatten Nord AS and Norled AS, also have a long standing and strong position in the industry. Torghatten Nord AS was founded in 1878, actually holds 27% of the LNG-fueled ferries and 16% of the electric-powered ferries. Whereas Norled AS (earlier Tide Sjo AS) launched its first passenger ferry in 1964, it has also launched the first all-electric ferry and the first hydrogen-powered ferry globally. The company holds 12% of the LNG-fueled ferries and 18% of the electric-powered Norwegian-flagged ferries. Thus, the early adopters of the alternative energies in



(*) figures till October, 2021.

Source(s): Norwegian Maritime Authority (2021), Norwegian Coastal Administration (2021) and Ferry-site.dk (2021)

Figure 5. Shares of deployed fleet for LNG/dual and electric/hybrid ferries (2000–2021*)

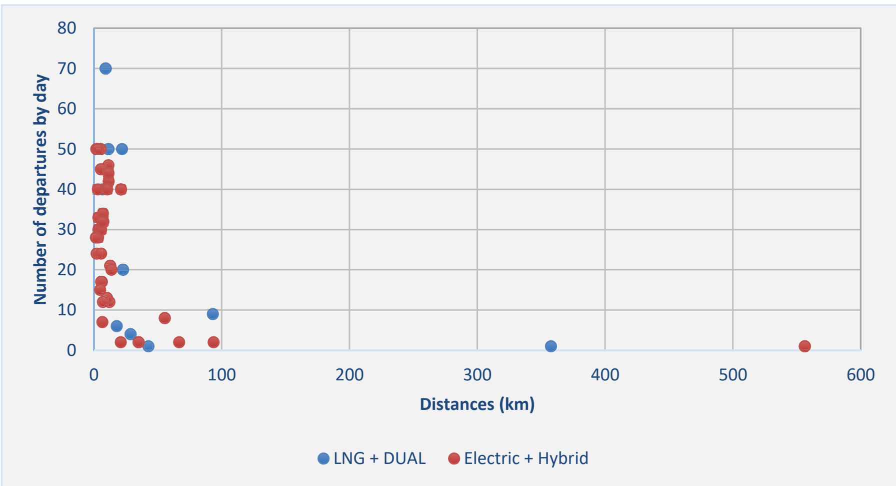
Norwegian ferry markets are companies with perfect knowledge of the business dynamics and a solid operational experience. It could be suggested that this level of business knowledge allows them to deal more efficiently with market uncertainties associated with the adoption of new technologies of propulsion.

The large majority of ferry services are comparatively very short shipping routes. Less than 25 km of distance traveled for most electric and hybrid ferries, and less than 50 km for most LNG- and dual-fueled ferries (Figure 6). Shorter distances to sail appear to be a definite advantage when developing and introducing new propulsive energies and technologies: (1) there is less pressure on the technology to provide long range capacities, (2) the new energy distribution networks necessary to « refuel» the vessels does not need to be extensive to start with and (3) from a maintenance perspective shorter routes imply more frequent calls into port where mechanical issues can be dealt with. Indeed, no ferry operator will adopt an alternative energy if the terminal at ports served by its vessel cannot offer the need corresponding energy distribution infrastructures.

For illustration, the authors have demonstrated in a previous contribution (the authors, 2020) that the LNG as a marine fuel in Norway has been developed gradually and at different scales, starting short range local markets. The availability of LNG also appeared a determining factor in explaining where such initial short range service where first implemented.

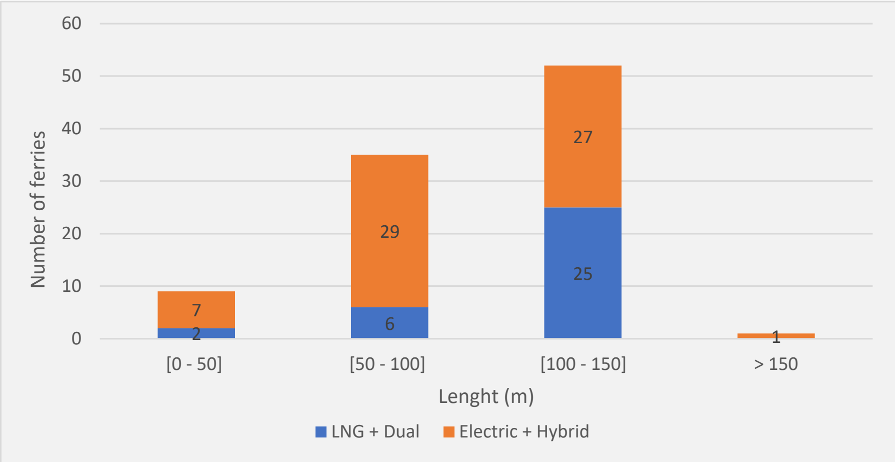
5.4 Technical uncertainties: medium-sized ferries and hybridization strategy

In shipping, there is a consistent focus on the potential application of different alternative energies, with some of them posing significant challenges to ship design. The available volume on board a ship is the primary constraint in choosing the type of energy solution. Therefore, the size of the ships in relation with the cargo carrying requirements is one of the crucial design criteria. The case study shows the *early adopters* to be carriers with small- and medium-sized ferries. As shown in Figure 7, most ferries have a length comprised between 50 and 150 m that could be explained by the uncertainty related to the development of appropriate infrastructures. The new energy carriers will first be utilized in smaller short-sea



Source(s): CompiledfromMarinetraffic.com(2021)and Vesselfinder.com(2021)

Figure 6.
Distances and regularity of the services of LNG + DUAL and electric + hybrid ferries



(*) figures till October, 2021.

Source(s): Norwegian Maritime Authority (2021), Norwegian Coastal Administration (2021) and Ferry-site.dk (2021)

Figure 7.
Ferries using alternative energies by length (2000–2021*)

vessels because the ferry market appears more flexible toward introducing alternative energies than the ocean-going sector. Indeed, as technologies mature and the infrastructure develops, each new energy can be used in larger vessels provided that global infrastructure becomes available.

Hybridization offers a great level of flexibility to the early adopters since the previously dominant energy technology is not entirely dropped at once: reversal the «old ways» remain possible. The choice of hybridization strategy either through the utilization of dual fuels (e.g. diesel MDO (marine diesel oil), HFO (heavy fuel oil) with LNG) propulsion system or hybrid (e.g. diesel or LNG with electric batteries) propulsion system reduces the risks inherent to alternative energies adoption. As shown in Figure 8, more than half of the accounted vessels (53 ferries) using alternative energies are hybrid (electric with LNG or diesel). In contrast, 31 ferries have an propulsion system using solely an alternative energy (LNG or electric batteries). The strategy of the early adopters is highly related to the provision of bunkering or recharging installations in the ports. Hybridization offers a flexible solution when the availability and distribution network of the chosen alternative energy – or its fluctuating price – remain uncertain.

Generally speaking, converting existing vessel from a propulsion system to another one or adding another propulsion system using a new type of energy or fuel is an option for reducing the total cost of deploying an alternatively propelled ferry as construction of new ferries requires high capital investment, efforts and time. Nevertheless, as illustrated in Figure 9, the number of new construction ferries for each alternative energy is higher than that of retrofitted ferries. Conversion projects are even fewer for electric-powered ferries than LNG-fueled ferries. This not surprising since LNG burning engines are technological closer and easier to retrofit into conventional vessel than electric propulsion. Investing in new ferries using alternative marine energies demonstrates a high level of confidence from the ship-owners toward the future of the chosen alternative energy. It is particularly true for the electric and hybrid ferries, where about 80% are new construction against 66% for LNG and dual ferries.

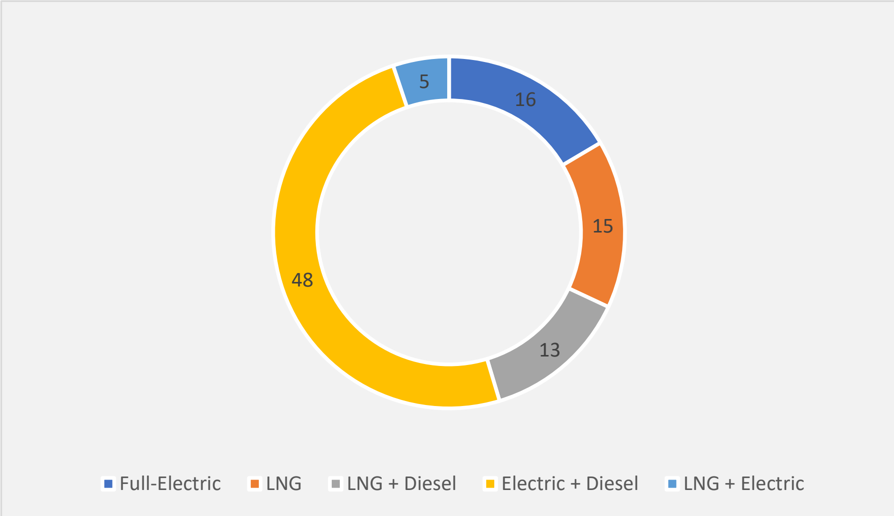


Figure 8.
Number of Ferries by type of propulsion system (2000–2021*)

(*) figures till October, 2021.

Source(s): Norwegian Maritime Authority (2021), Norwegian Coastal Administration (2021) and Ferry-site.dk (2021)

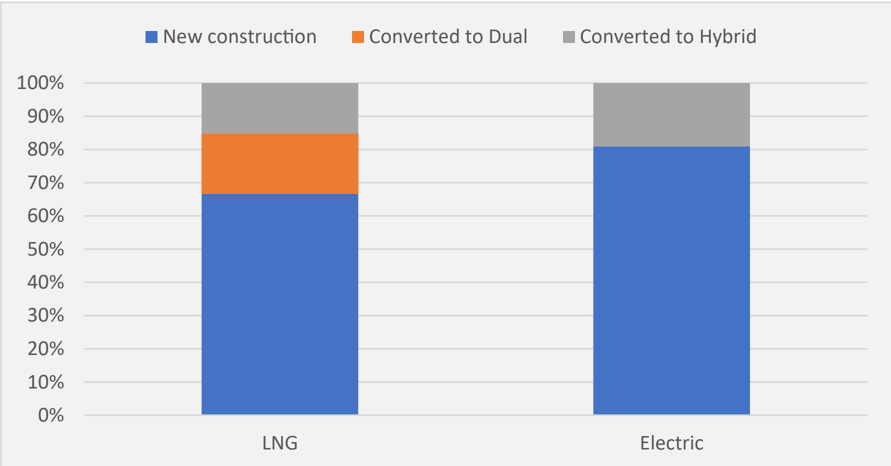


Figure 9.
Percentage of retrofitted/converted ferries (2000–2021*)

(*) figures till October, 2021.

Source(s): Norwegian Maritime Authority (2021), Norwegian Coastal Administration (2021) and Ferry-site.dk (2021)

6. Conclusion

Key findings revealed similarities between the LNG/dual-fueled ferries segment and the electric/hybrid-powered ferries segment:

(1) Both markets are highly concentrated, where only a few companies have nearly the totality of the market shares. Even if this high concentration level mitigates risk

aversion by reducing the number of competitors, it concentrates the market between very few players.

(2) Both ferries segments are dominated by medium-sized ferries, and the services offered are short-route services with a high level of regularity.

(3) Both ferries segment benefit from a high level of public supports from the national government and the European authorities driving to reduce their risk perception on these alternative energies.

Nevertheless, the substantial increase in the number of electric and hybrid-electric powered ferries during the last few years, adding to the percentage of new construction, demonstrates some disparities regarding the LNG and dual-fueled ferries segment. The "chasm" of uncertainties seems to be through for the electric and hybrid ferries segment. As some authors did advocate, one could assume that the LNG constitutes a transitional fuel in short-sea shipping, especially since the global ambitions are toward zero-emission energies. One could also assume that the utilization of the new alternative energies may be specialized regarding the specifications of the maritime routes (distances, domestic or cross-border), the services (regularity, demand level), and the technical and logistics attributes. It is worth mentioning that even if it was not directly investigated within the scope of this paper, the investments in appropriate infrastructures such as bunkering installations or electric recharging installations within ports have an essential role to play in reducing uncertainty and influence on investors' decisions. At last, other alternative marine energies are currently being experimented with (e.g. hydrogen, ammonia, etc.). It will be interesting to scrutinize how the adoption of these new energies will evolve in the future and especially into the Norwegian ferry markets.

What are the broader implications for maritime business researchers and practitioners of our transition study to alternative propulsion technologies in the Norwegian ferry market? We suggest three significant elements. First, if the combustion marine engine running on diesel or heavy fuel oil remains the current mode of propulsion for a vast majority of today's world fleet, its hegemony is challenged. Ships' operators developing new designs with a shipyard or contemplating reconversions have increasing propulsion options. As a result, a new variable is being added to fleet deployment's fundamental buy/sale equation, adding more complexity for shipping companies' managers. Second, for some niche markets, electric batteries are a currently workable option among these possibilities, as exemplified in our case study. This was considered highly unlikely just a few years ago, given weight and range issues. This in itself is an exciting reminder that technological change can occur at a fast rate under high market pressure. A third element to watch as ships' propulsion modes are transforming is wetter, or not a single technology will come to replace the fossil fuel engine across all markets? Indications from the specific ferry market in Norway suggest that the future world fleet could employ various propulsion technologies. Specific modes could prove optimal only in given conditions defined by such factors as route length, regulations, port infrastructures or freight value. This eventual segmentation at a larger scale of ships' propulsion technologies appears an essential element to monitor in future research.

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