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Special ship design and ocean space multi-use synergies

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ABSTRACT

This paper introduces the concept of synergistic multi-use between offshore wind and other sectors in the ocean space, to the ship design audience. We study the opportunities that arise when using special ships to service several ocean sectors, thereby realizing some of the synergies for multi-use. Multi-use of the ocean space becomes desirable due to the increasing demand for marine area by growth sectors like offshore wind and offshore aquaculture. We find that the primary opportunities to realizing multi-use synergies from vessels lie in the operational phase. Logistical support, crew transfer, emergency response, accommodation, and some inspection and repair tasks are sufficiently similar across offshore wind and fish farming that multi-use should be considered. The application of the synergistic multi-use concept also extends to other special ship types, such as offshore support vessels serving oil and gas production.

KEY WORDS

Special ships; Blue Economy; Ocean Space; Multi-use; Shared logistics

INTRODUCTION

The ocean is at the forefront of solutions to many of the world's most pressing problems, including the transition to green energy and more sustainable protein, for instance from seafood. Addressing the fight against climate change, the *High Level Panel for a Sustainable Ocean Economy* (Hoegh-Guldberg et al., 2023) recently suggested a number of mitigation opportunities across seven ocean-based sectors. Policy and market dynamics in key sectors that shape the blue economy suggest that buildout of renewable energy and food production in the ocean space will be highly geographically centralized. Locations with desirable ocean conditions will be highly sought after by several actors, meaning that there are opportunities for cross-sectoral collaboration and synergies, as well as a risk of competition for space (DNV, 2023d).

In Europe, the EU ambitions for offshore renewables have been reaffirmed by the countries surrounding the North Sea. The Ostend Declaration of April 2023 aims to grow offshore wind in the North Sea to 300 GW by 2050, signed by nine countries. Addressing the heightened concerns about use of marine space, the EU Maritime Spatial Planning Directive now requires all EU countries with a coastline to develop and implement a maritime spatial plan, to align energy production with other societal objectives depending on the ocean space. Following the introduction of MSP in the EU, a plethora of research projects have investigated multi-use as a solution where ocean industries make use of the same core or peripheral infrastructure (Schupp et al., 2019).

At DNV, multi-use challenges and opportunities are currently explored by the Ocean Space research programme. The *Ocean's Future to 2050* suite of reports provide forecasts of the Blue Economy on a global scale (DNV, 2021; DNV, 2023d), following the system dynamics methodology also applied in DNV's *Energy Transition Outlook* (DNV, 2023a). In 2023 we published our *Spatial Competition Forecast* (DNV, 2023d), showing that offshore wind area use will instigate competition for space among industries operating in the ocean. Later in 2023, we initialized a new project MARCO (*MARine CO-existence scenario building*), which investigates co-existence through a range of solutions turning the area conflict into a range of opportunities,

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among them industry multi-use interlinkages (DNV, 2022c). Special ships are among several enabling infrastructures for multi-use, and already employed in service of many offshore industries, like offshore O&G, wind, and aquaculture.

The main purpose of this paper is to explore the challenges and opportunities for special ship design that targets multi-use synergies, which could exist when several ocean industries operate in close proximity of each other. How much of the vessel logistics involved in the operation of an offshore wind farm can be shared with an offshore fish farm? Which functionality is needed, and to what extent do the required vessel functions overlap? Can offshore charging systems near wind farms make battery-powered service vessels a reality? Can the chartering of service vessels with relevant functionality be shared between wind operators and fish farmers? How much would this reduce the OPEX of fish farmers and offshore wind operators?

Experiences from offshore support segments ten years back suggests that stakeholders in the wind and aquaculture sectors should take a cautious approach to designing in multi-functionality. Back then, ship design practice adapted to a "more is better" approach where more demanding operations, new rules and regulations, and a need for market differentiation allowed more costly vessels to be built, supported by high oil prices and chartering rates (Garcia et al., 2016). If multi-use opportunities for special ships are to materialize in an economically sustainable fashion in the emerging blue economy sectors, ship design needs to take a broad systems approach, and be conducted in smarter way, with respect to multi-functionality.

The paper is structured as follows: First, we review the relevant literature on marine multi-use and special ships. Second, we assess the primary drivers of multi-use between ocean industries. Third, we review the special ship types servicing offshore wind and aquaculture, through typical project lifecycles. Fourth, we assess the opportunities and challenges associated with multi-use that arises for special ships. Finally, we conclude.

LITERATURE REVIEW

We provide a brief literature review on key research across three distinct, but related domains. First, most advances related to the concept of multi-use recently has seen this in relation to the process of marine spatial planning, and hence has gained a lot of interest not only among engineers, but also from policymakers and marine science communities. Second, parts of the literature on design of special vessels that has ventured into concepts like multi-functionality, modularity, and future uncertainty, is highly relevant. Third, special ships are always part of a wider logistics system and it is difficult to understate the impact of the logistics system design on the capabilities needed in each ship.

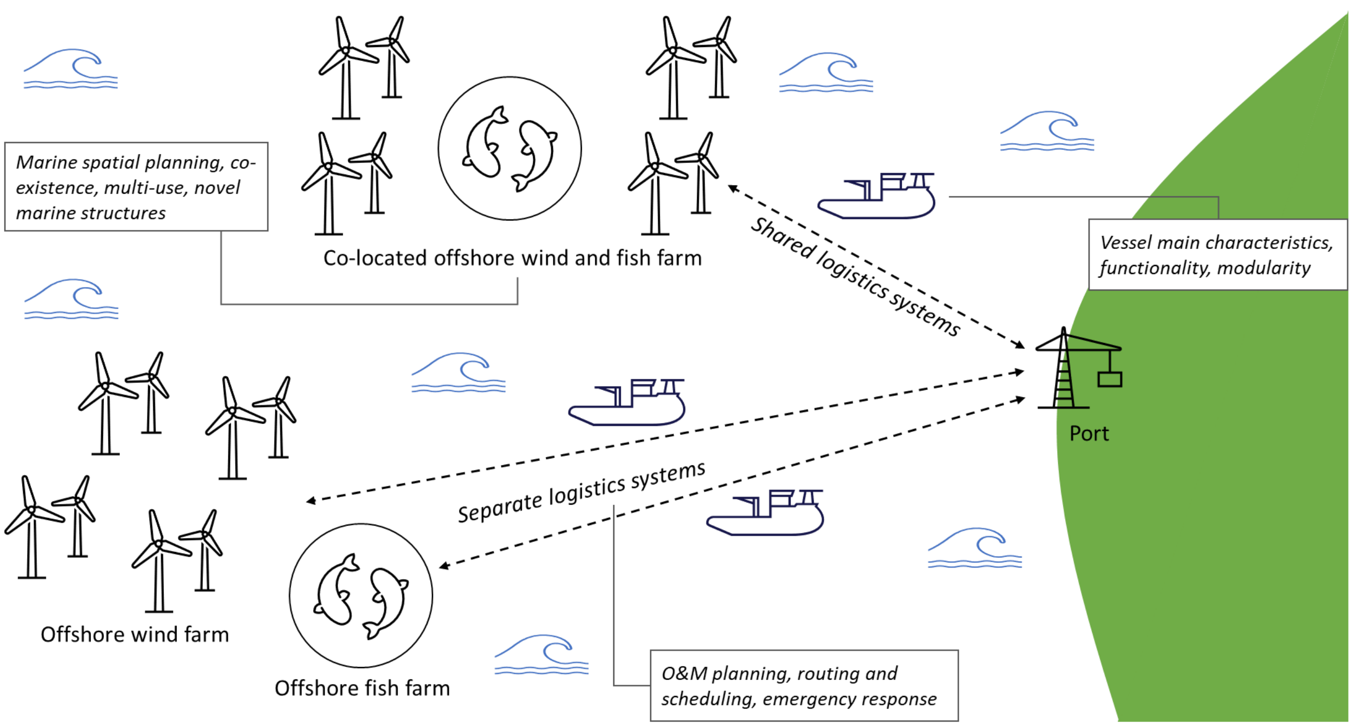

Figure 1: The main idea of the paper and topics addressed in the literature review.

Synergistic multi-use in marine spatial planning

Marine Spatial Planning is defined as “the public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic and social objectives that have been specified through a political process” (Ehler & Douvere, 2007). In the EU, the Maritime Spatial Planning directive mandates every member state to introduce the concept into national legislation. On a global level, more than 75 states worldwide have some type of MSP process in place (Ehler, 2021).

Introducing MSP provides agency to stakeholders across ocean domains. However, in a world with rapidly evolving ambitions to build out offshore wind, the existence of trade-offs between societal objectives like energy production, seafood production and nature protection, could still lead to situations where some stakeholders remain unsatisfied. For instance, this has been seen between fishermen and the offshore wind sector over concerns that offshore wind will limit access to fishing grounds, when policymakers decide to prioritize renewable energy production. In some cases, considering synergies between sectors can reduce risk of conflict, and lead to identification of win-win opportunities.

Several large research projects have received funding from the EU to study the potential for multi-use of the ocean space, in order to reduce the potential for stakeholder conflicts, and to realize synergies. *MUSES (Multi-Use in European Seas)* developed seven multi-use case studies with a specific combination of production systems at a specific geographic location. Combinations with relevance to the food and energy sectors included offshore wind-wave energy, offshore wave energy-aquaculture, offshore wind-fisheries, offshore wind-aquaculture, and offshore O&G decommissioning with repurposing (Bocci et al., 2018). *MARIBE (Marine Investment for the Blue Economy)* investigated 24 sectoral combinations offshore, with more in depth demonstration of the most promising concepts (Dalton et al., 2019). Ongoing projects like OLAMUR (*Offshore Low-trophic Aquaculture in Multi-Use scenario Realization*) introduce pilot test sites for low-trophic aquaculture (e.g. mollusc and seaweed farming) inside existing wind farms (OLAMUR, 2024). Similar to the multi-use term, the concept of *Marine business parks* has been proposed by the *Center for the Ocean and Arctic* at the Arctic University of Norway, in a collaborative project involving stakeholders across the Norwegian offshore energy, seafood, shipping, non-governmental organization, and research sectors (Hersoug & Mikkelsen, 2022). Very little research has been done on the opportunities for designing special ships for this context.

In summarizing the results of the EU project *MUSES*, Schupp et al. (2019) provide a typology for multi-use, stretching from multi-purpose platforms to repurposing of offshore infrastructure, classified along four criteria; spatial, temporal, provisional, and functional. Table 1 introduces the typology proposed by Schupp, with examples prepared by Pettersen et al. (2023). In this paper, we build further on the concept with the second highest level of integration, called *symbiotic multi-use*. However, we will use the term *synergistic multi-use*, to emphasize more strongly the joint efforts by two actors to create an improved outcome for both, rather than to presume that a *symbiosis* emerges from the actor’s mutual dependence. Under the concept of *synergistic multi-use*, offshore production systems may depend on the same logistics support and are located within proximity of each other. Hence, the two production systems make use of the *same space*, at the *same time*, and sharing *peripheral* infrastructure and services. Among several examples of multi-use, Pettersen et al. (2023) identify examples of potential for synergistic multi-use that includes special ships, highlighted in bold in Table 1.

As opposed to synergistic multi-use, multi-purpose platforms would reflect a fully integrated structure where a single infrastructure accommodates two or more distinct ocean uses. This means that multi-purpose platforms are also tightly functionally connected. Fully integrated multi-purpose structures face numerous barriers, both technically, economically, and regulatory (Van Den Burg et al., 2020). Naturally, they face difficulty meeting key design principles like functional independence (Braha and Maimon, 1998). Reporting on the results of the *MARIBE* project, Dalton et al. (2019) found that very few concepts for large-scale multi-use platforms were economically viable, according to a generalized “levelized cost of output” metric developed to compare unit costs for different production systems combined on a single marine platform. Other difficulties for scaling multi-use at sea are discussed by Van Den Burg et al. (2020) who, through a synthesis of the *MUSES* and *MARIBE* results, and other research on the topic, present an overview of the key barriers to multi-use, including economic, technical, social, administrative, legal, and environmental ones. Differing perspectives on risk among the stakeholders involved in multi-use will also influence the opportunity space, with distinct sector-specific frameworks dominating the sectors that will be involved in a multi-use concept (Van Hoof et al., 2020).

Table 1: Typology of multi-use concepts by level of system integration (Pettersen et al., 2023), based on Schupp et al. (2019). Examples in bold are particularly relevant for special ships.

Typology	Spatial	Temporal	Provisional	Functional	Description
Multi-purpose	X	X	X	X	Same area, same time, sharing core infrastructure and services
Examples	Combined floating offshore wind structure and finfish cage aquaculture Floating desalination plant powered by wave power Energy islands acting as hubs for grid connection and green hydrogen production plants				
Synergistic use	X	X	X		Same area, same time, sharing peripheral infrastructure and services
Examples	**Shared logistics systems and service vessels for offshore wind and aquaculture operations in the same area** Electricity from offshore wind to replace gas turbines on offshore oil and gas installations **Offshore wind farms to act as charging stations for electric ships** Floating solar photovoltaics replacing diesel generators at fish farms Integrated multi-trophic aquaculture: Fish farming combined with farming of low-trophic species like molluscs and seaweed				
Co-location	X	X			Same area, same time
Examples	Adoption of passive fishing gear to reduce risk of gear interference with offshore wind structures Requirements to reduce risk for trawling over pipelines and subsea structures				
Repurposing	X				Same area, subsequently
Examples	Ships and offshore structures decommissioned to become artificial reefs Area traditionally used as fishing grounds repurposed to fixed offshore wind farms				

Synergistic multi-use and research on design of special ships

Synergistic multi-use as described above will rely heavily on sharing of provisional functions, primarily provided by special ships that "go to sea to do something" (Andrews, 2018), besides transportation.

At the previous IMDC, Erikstad & Lagemann (2022) reviewed the state-of-art on ship design methodology, identifying four primary design strategies taking a hold, beyond the traditional design spiral approach; optimization-based, set-based, system-based, and configuration-based design. They argued that most design practice combines the four, but for practical purposes, the system-based approach (Erikstad & Levander, 2012) based on a "needs-function-form" mapping process, provides a useful starting point for understanding the role of special ships in synergistic multi-use. System-based ship design is a mission-centric approach where a good understanding of the market conditions and the main operational needs enables "right-sizing" of the vessel before concept exploration and design iterations take place. "Right-sizing" is becoming an essential aspect of teaching vessel owners in offshore wind service to specify requirements that correspond to the intended operational needs, rather than adding additional capabilities "just in case" (The Naval Architect, 2024).

Designing vessels for synergistic multi-use, considering the distinct needs of offshore wind and aquaculture markets, will require a deflection from previous run ins with concepts like multi-functionality in offshore support vessels. Up until nearly 10 years ago, offshore support vessels were increasingly designed for multi-functionality under the guise of high chartering rates due to high oil prices. Due to their high operating costs, some of these highly functional vessels turned "multi-useless" (Gaspar et al., 2015), as they could not find profitable work in a context with day rates dropping when the oil price collapsed (Garcia et al., 2016). The next generation of special ships, whether serving offshore wind, aquaculture, or the two sectors in combination, should adopt smarter design practices, aimed for instance at enabling future changes in configuration and mission-related equipment at a lower cost.

The EU-funded *NEXUS* project (*Next generation support vessels providing safe and more efficient offshore wind farm services)* investigated possible conditions for game-changing service operation vessels, with the objective of reducing maritime logistics costs for offshore wind maintenance by 20%. Puisa et al. (2021) analyze the safety of SOV operations at a wind farm by introducing the concept of system variability as a proxy for the likelihood of incidents, finding that the most safety-critical interface during operations is between SOV gangway and the turbine. Also as part of the NEXUS project, the benefits of variable speed engines for fuel saving on vessels that spend a significant proportion of their operating profile in dynamic positioning (DP) were investigated (Holmefjord et al., 2020). Holmefjord et al. (2020) find a 20% fuel saving on an analysis of the Service Operation Vessel (SOV) *Edda Passat*. Similarly, in an earlier study by Lindstad et al. (2017), batteries were evaluated as a solution to hybridize offshore support vessels, thereby reducing the need for running redundant combustion engines at low loads when operating in DP mode.

Approaches to handle future uncertainty at the design stage will be needed to address new ocean sectors, exploit synergies in logistics support, new fuel types, and emerging mission-related requirements. To avoid overdesign, modularity and flexibility is desirable, and fits well with a "design for sustainability" perspective, where ship design considers long-term economic, environmental, and social objectives (Erikstad & Lagemann, 2022). Core design principles like modularity and flexibility are increasingly well-addressed in industry practice as a means to adapt to the energy transition (Willumsen et al., 2023). "Prepared for X" class notations exemplify the willingness of ship owners to pay a premium to prepare the vessel for future functionality, particularly in relation to upcoming fuel types (DNV, 2022b), exemplifying the designing of real options "into" ships. A number of recent vessel conversions of platform supply vessels to service operation vessels also illustrate that the industry sees retrofit as a more cost-efficient and sustainable option that newbuilding (Ulstein, 2022), particularly when the underlying marine platform is sufficiently versatile. Various methods have been developed to support offshore ship design viewed as decision-making under uncertainty with the goal of enabling flexibility through the lifecycle (Gaspar et al., 2015; Pettersen et al., 2020; Rehn et al., 2019; Zwaginga et al., 2021; van Lynden et al., 2022). In the offshore wind sector, Zwaginga et al. (2021) consider the uncertainty in future design requirements for installation vessels in offshore wind, for instance related handling turbines with increasing size and capacity. Similarly, van Lynden et al. (2022) apply epoch-era analysis (see for instance Gaspar et al. (2015)) to generation of future market scenarios for offshore wind installation vessels, combining this approach with parametric ship design modelling.

Pettersen et al. (2020) provide examples of latent capabilities existing in complex special vessels, enabling these vessels to perform a range of operations for which they were not originally designed, of particular importance for improving emergency preparedness. Latent capabilities refers to functional attributes vessels were not intentionally designed for. The idea of latent capabilities can be a powerful one in a context where possibly stranded assets from O&G service segments can be repurposed, possibly without large design changes, to new market segments. In the co-existence between offshore wind and other ocean users, one can consider concepts that use fishing vessels for ocean observation (Van Vranken et al., 2023), for instance providing new knowledge about the environmental impact of offshore wind. The use of fishing vessels for oil spill response or other emergency response tasks are also a prominent example of this (Pettersen et al., 2020).

Logistics of synergistic multi-use

A big operations research literature exists on use of optimization and simulation methods applied to complex special vessels and their logistics, serving both offshore oil and gas (Fagerholt & Lindstad, 2000), offshore wind (Irawan et al., 2023; Lazakis & Khan, 2021), and marine aquaculture (Slette et al., 2022, 2023). To the knowledge of the authors, very few studies have addressed the logistics of synergistic multi-use as described above, outside of emergency preparedness where e.g. oil spill response systems will address accidents regardless of in which industry they originate. We mention a few interesting examples from recent years, which has addressed logistical aspects relating to new ocean industries.

Lazakis & Khan (2021) propose an operational planning methodology for the optimal short-term route planning and scheduling of SOVs and crew transfer vessels (CTVs) taking into consideration characteristics for the wind farm, turbine failures, and the two vessel types, as well as environmental conditions. They find that the operational window increases when SOVs and CTVs are used together. Similarly, Irawan et al. (2023) construct a two-stage stochastic programming model accounting for weather uncertainty, and find that SOVs improve offshore wind maintenance efficiency, and that using SOVs in combination with a safe transfer boat (daughter craft) minimize the total maintenance costs. For the cases studies, SOV and the safe transfer boat combination are found to reduce maintenance costs by up to 70% over approaches that rely on CTVs.

Within aquaculture, Slette et al. (2023) provide an integrated simulation-optimization framework to evaluate the performance of alternative fleets composed of a combination of specialized vessels or multi-purpose vessels that service a set of fish farms. They find that the performance with respect to utilization of weather windows is generally higher for fleets composed of multi-purpose vessels, as appropriate functionality does not become a limiting factor when routing for the next service mission. Furthermore, they find that letting service vessels serve localities that are not correlated in terms of weather, also improves overall utilization of the fleet. The logistics of fish health emergency response has also been studied in another paper by Slette et al. (2022), focusing on the cost-benefit trade-off of dedicated emergency response vessels in fish farming.

The *North Sea Energy programme* report on *The Potential of Shared Offshore Logistics* analyses key scenarios for sharing of offshore logistics in the future offshore energy system of the southern North Sea (Omrani et al., 2022). The report focuses on logistical needs in the energy sector, considering wind farms and oil and gas platforms that increasingly turn to producing blue hydrogen and capturing carbon. In the scenario of the Dutch “Hub West 1”, which includes the Hollandse Kust Noord wind farm and six O&G platforms close by, they find that 8% of the wind farm OPEX (1.9 MEUR) can be saved by using a shared logistics concept that uses CTVs for personnel transit to the oil and gas installations, without compromising the availability of the offshore wind farm. The effects of reducing PSV usage are not described in detail in the study but gives rise to the suspicion that the PSV functionality to be replaced is not sufficiently accounted for.

On top of sharing costs through multi-use synergies, European shipping will increasingly be forced to report on emissions (DNV, 2023b), meaning there is also an environmental dimension to the sharing of vessel capabilities among actors in the ocean industries.

KEY DRIVERS FOR MARINE MULTI-USE

DNVs efforts to forecasting the Blue Economy, the *Ocean’s Future to 2050*, provide reference modes for developments across the ocean industries, a summary of which is shown in Figure 2. Offshore wind will by far be the fastest growing segment to mid-century and is forecast to see around a 20-fold growth between 2024 and 2050, as shown in blue. The floating offshore wind subsegment is forecast to rise even faster, but from a significant lower starting level than bottom fixed turbines, and is therefore not included in Figure 2. Marine finfish aquaculture, i.e. the farming of high-value fish like salmon in sea-based cages is forecast to triple, as shown in green (DNV, 2023c). Offshore fish farming grows much faster than other marine aquaculture, also growing around 20-fold, albeit from a much lower starting point than offshore wind. The prognoses of key developments within major ocean industries in Figure 2 is based on DNV (2023a), (2023c) and (2023d).

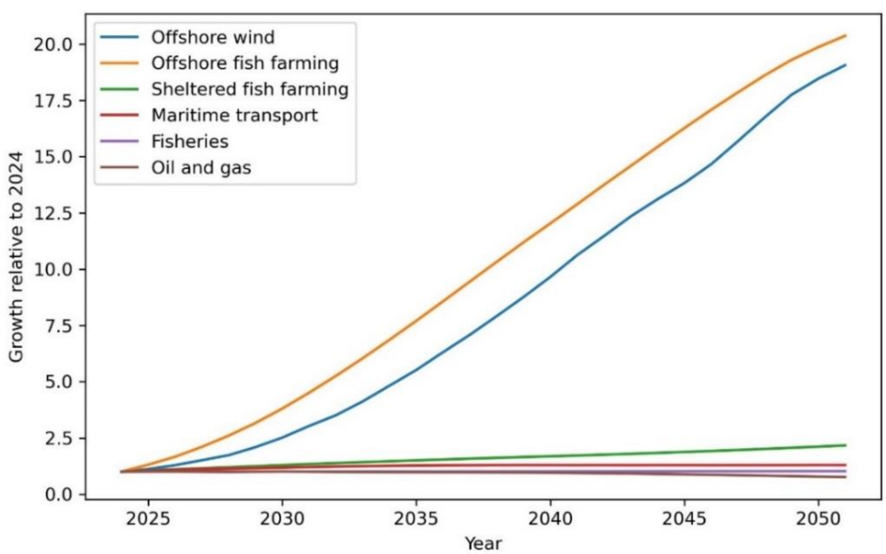

Figure 2: Prognosis for development in key ocean industries

Offshore wind

Offshore wind is the single, fastest growing sector in the ocean economy, spurred on by the need to decarbonize the energy system. By 2050, DNV (2023a) forecasts the installed capacity in the offshore wind sector to reach around 1,600 GW, which means 100,000 turbines globally if the average turbine rating by then reaches 16 MW. In Europe alone, the installed capacity reaches more than 400 GW, implying approximately 25,000 turbines. If all turbines globally require planned maintenance twice per year, more than 500 turbines need to be serviced every day, before considering unscheduled maintenance and repairs. With this, there will be a large demand for logistical support throughout the field lifecycle.

Geography largely determines the location of offshore wind, with wind speeds and proximity to existing electricity grids and other infrastructure, as some examples. Fixed offshore wind farms are build using monopiles or jackets, which may also be the technically preferred solution down to around 80-100 m water depth, further limiting the availability of sites. Floating offshore wind is currently developed for deeper waters, with Hywind Tampen a first example of an industrial-scale floating wind farm built to electrify oil and gas production (Equinor, 2023). Future power-to-X solutions like green hydrogen production could alter the dependency of the sector on grid connectivity, but would introduce other logistical challenges, for instance related to hydrogen (DNV, 2023a).

In Europe, the geography of the North Sea basin makes it the most attractive sea basin for developments, with around two-thirds of installed capacity in 2050 (DNV, 2023d). Even if the North Sea will be the main market for European offshore wind, price cannibalization due to weather correlations between offshore wind fields, spatial conflicts at the most attractive sites, etc, will increasingly cause capacity to be developed far from shore and in deeper waters, where floating solutions will be needed.

Offshore wind, as a quickly emerging market segment, has seen rapid declines in cost (levelized cost of electricity (LCOE) over its first twenty years. In the last two years, high costs of raw materials and supply chain bottlenecks (ports, manufacturing, installation vessels) has contributed to large increases in the LCOE, resulting in delay of many investment decisions and poor turn-out in high profile offshore wind auctions (Equinor, 2024; Grønholt-Pedersen, 2023). Nevertheless, most forecasters believe this to mainly be a short-term problem, as many other industries face similar inflationary pressures. Over the longer run, LCOE is forecast to halve for fixed offshore wind between 2020 and 2050 and halve for floating offshore wind between 2030 and 2050 (DNV, 2023a).

Offshore wind is a capital-intensive industry as shown in Figure 3, based on data from the Crowne Estate and ORE Catapult (2019). Purchasing major components like turbines and balance of plant (non-generator supporting infrastructure like foundations, cables, etc.) constitutes around 40%, while installation costs add another 20%. In the operational phase, operations and maintenance costs contribute almost 30%.

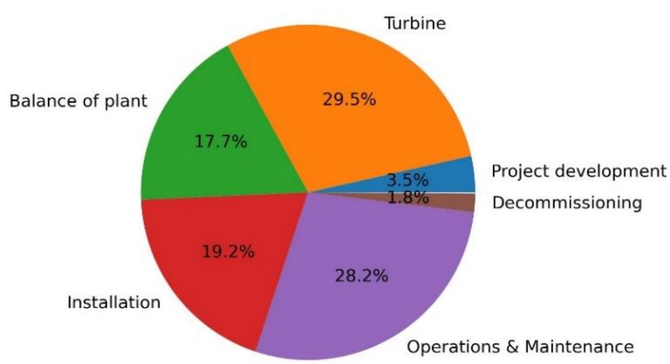

Figure 3: Generic levelized cost of electricity breakdown for offshore wind (based on The Crowne Estate and ORE Catapult, 2019)

As a relatively new market, Clarkson's Research (2024) historical time charter rates for key subsegments are available back to 2020 only (see Figure 4). In the three years following, there has been a significant increase in the chartering rates, with rates for e.g., large SOVs with walk-to-work (W2W) functionality and accommodation for more than 40 people have almost tripled from slightly more than 20,000 EUR/day to more than 55,000 EUR/day. In 2023, day rates for these vessels exceeded those of AHTS vessels operating in the North Sea. Smaller W2W vessels and non-W2W SOVs saw lower day rates over this period, owing to less functionality and hence likely lower operability (e.g. lack of gangway limiting time windows with sufficiently small waves). Compared to traditional offshore support segments, offshore wind will likely see lower rates, but likely also less volatility (The Naval Architect, 2024).

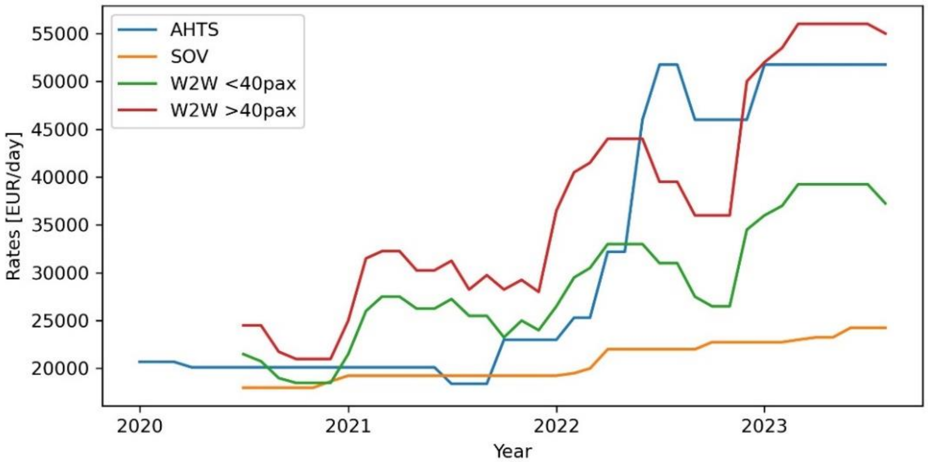

Figure 4: Charter rates for key vessel segments in offshore wind operations (Clarkson's Research, 2024)

A key driver for increasing vessel sizing and more advanced capabilities is the fact that offshore wind farms are being installed further from shore and in deeper waters. This is most critically pronounced in the construction phase, where novel solutions that can bring down the cost of installation will be desired. Also in the operating phase, new logistics support solutions may be favorable, due to the increased distance to shore. To great challenge will be for ship designers to advance offshore wind service vessel capabilities without adding excessive costs.

Offshore fish farming

Offshore fish farming is likely to become a fast-growing subsegment of marine aquaculture. Most current marine fish farming operations take place in benign waters (e.g. Mediterranean seabass and seabream production) or sheltered waters (fjords in Norway, Scotland, Iceland, Canada, or Chile). Over the last ten years, increasingly exposed localities have been tested out, particularly in Norway and the Faroe Islands. Some of the most promising concepts for offshore fish farms were awarded with development licences, with some key characteristics shown in Table 2 (Pettersen, 2022).

A key feature of the development licenses was that they allowed licenses free-of-charge for concepts with a sufficient degree of innovativeness. However, despite the introduction of development licenses several years, the regulatory framework for offshore fish farms is still lacking, causing many investments to be delayed in the short term as the developers see limited opportunity to scale to the increased number of units to trigger sufficient investment cost reductions. Another recent showstopper has been the decision that offshore fish farms will not be liable for a new resource rent tax, a scheme that would have opened for offsetting expenditures on offshore projects against high profits earned in coastal aquaculture.

Table 2: Some offshore fish farms awarded development licenses in Norway (based on Pettersen, 2022)

Name	Owner/operator	Concept description	Capacity [tonnes]	Operational year
Ocean Farm 1	SalMar Aker Ocean	Ocean fish cage based on offshore technology	6,000	2017
Havfarm Jostein Albert	Nordlaks	Ship-shaped ocean fish cage	10,000	2020
Arctic Offshore Farming	SalMar Aker Ocean	Semi-submersible fish cage	3,000 x 2	2021
Smart Fish Farm	SalMar Aker Ocean	Semi-submersible ocean fish cage	19,000	Planned 2022 (delayed)
Spidercage	Nova Sea	Heave-compensated, wave breaking, semi-closed ocean fish cage	3,120	Planned 2023 (delayed)

In the longer run, regulatory uncertainties will likely be sorted out, and one can expect other countries to explore offshore aquaculture including multi-use solutions, in Europe and beyond. Outside Europe, progress on offshore fish farming is also happening in China. A first structure called "Deep Blue" was launched in 2018 but saw operational problems and made its first harvest of Atlantic salmon in 2021 (Pettersen, 2022). Following this, China has developed a variety of concepts for a number of species. The country also has high ambitions for offshore fish farming, e.g. as reported on by Feng (2023). DNV (2023c) finds that the offshore fish farming sector globally achieves a 7% market share by 2050.

A generic production cost breakdown for sheltered aquaculture is provided in Figure x, based on Iversen et al. (2020). Production costs in fish farming is mainly driven by the need for feed, which typically constitutes around 50%, or around 2.2 EUR/kg (Iversen et al., 2020). Investments, reflected through depreciations, constitute a relatively small cost share, but tripled over the period from 2006 to 2018 to 0.3 EUR/kg.

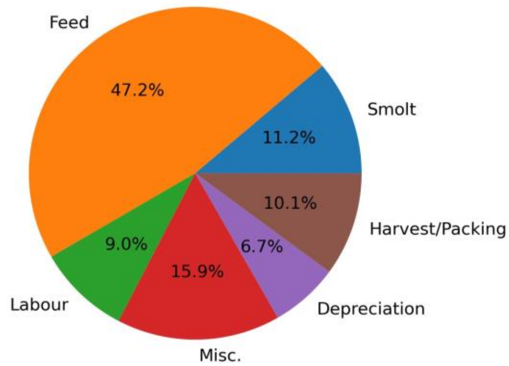

Figure 5: Generic production cost breakdown for sheltered aquaculture (based on Iversen et al., 2020)

For offshore fish farms, capital expenditures will make a much larger mark on production costs. Consider for instance a unit with a capacity of producing 3000 tonnes per year with a 25-year lifetime, and costing around 100 million EUR, then this would add around 1 EUR/kg to the production costs. To compete with existing aquaculture, offshore fish farming is therefore dependent on learning and scaling effects to reduce costs (Pettersen, 2022).

Additionally, with offshore locations comes more complex well boats and other specialized ships, which may further add to the costs. There is limited information about current chartering rates for well boats and other special vessels in aquaculture, with these costs often bundled with downstream processing activity in statistics (Iversen et al., 2020). For service vessels used for delousing operations, removal of sea lice, Iversen et al. (2017) cites day rates of up to 130 000 NOK, around 15 000 EUR. Some of the well boats retrofitted from laid off PSVs (AquaShip, 2021), will likely need to command rates similar to that market segment, which could be in the same range or higher.

Even though vessel-related costs constitute a relatively small fraction of costs associated with aquaculture today, more advanced vessels needed to support offshore operations, would require higher chartering rates. With a traditionally very cost-conscious industry (Iversen et al., 2020), and a low degree of willingness to be associated with the splurge associated with the golden-era of offshore support vessels (Garcia et al., 2016), offshore fish farmers might very well see the savings potential embedded in sharing of some logistical services with offshore wind.

Spatial impacts and benefits of sharing maritime resources

In area terms, 80% of the area reserved for permanent use by ocean industries will be taken up by offshore wind farms, not counting uses that are mobile, like shipping and fisheries, nor unproven offshore renewables (solar PV, tidal, wave power) (DNV, 2023d). Hence, by co-locating offshore wind with all other offshore installations (e.g. offshore oil and gas, marine aquaculture), the full potential of marine multi-use is estimated to reduce mankind's long-term use of marine area with 20%.

Apart from reducing the area footprint of marine use, this multi-use could come with potential synergies. Symbiotic use entails the use of marine space in a manner that exploits synergies, for instance by making use of shared peripheral infrastructures or services (Schupp et al., 2019). For example, there could exist a potential for cost saving when coupling the logistical support requirements of offshore wind with those of offshore aquaculture, if the production systems are in proximity of each other.

From the perspective of the overall production cost in aquaculture, or the levelized cost of electricity in offshore wind, chartering of vessels constitutes a relatively small share, indicating a need for further cost-benefit analyses for shared logistics concepts. Emerging regulatory and financial requirements can result in a stronger business case for the synergistic multi-use of special ships, as carbon pricing is introduced (DNV, 2023b), and offshore wind tendering increasingly emphasizes co-existence with other ocean stakeholders (DNV, 2023d).

From 2027, offshore ships above 5000 GT will be included in the EU Emission Trading System (ETS), and smaller offshore vessels will also be considered for inclusion in this scheme. With the EU ETS, carbon prices will be brought into the maritime sector for the first time. The ETS implies a cap-and-trade philosophy, where a declining number of emission allowances will be auctioned and traded in the market (DNV, 2023b). The carbon price will rise over time due to declining allowances available, and the costs will eventually add to chartering rates, making ship operations that drive fuel consumption more expensive. Emissions will need to be reported on a voyage level, to settle transactions related to the emission allowance costs.

Synergistic multi-use of vessels for co-located offshore wind and aquaculture can reduce fuel consumption during transit by cutting the number of voyages needed, if one roundtrip voyage can support several production systems. The transparency that is needed for the cost of allowances to be allocated to specific charter parties, could also provide novel opportunities to define contractual terms for splitting the cost of carbon among several charterers, e.g., a collaboration between an offshore wind operator and an offshore fish farm operator.

Besides the impact of carbon pricing and reporting requirements related to fuel consumption for the vessels themselves, co-existence is increasingly taken into consideration in the tendering processes for new offshore wind farms (DNV, 2023d; Pettersen et al., 2023). Showcasing multi-use concepts like the dual use of vessels for offshore wind and aquaculture during an offshore wind tendering process could strengthen future applications, depending on the

SPECIAL SHIP CAPABILITIES IN THE PROJECT LIFECYCLE

In this section, we introduce key vessel segments that support marine operations in aquaculture and offshore wind, in order to assess whether the distinct operations allow for some sharing of vessel capabilities. Figure 3 provides an overview of the main lifecycle phases of any offshore wind or offshore fish farming project, emphasizing the marine operations where there is a need for support from vessels. Green shows operations with a lot of commonalities, light blue shows offshore wind operations, and dark blue shows offshore fish farming operations. Dashed green boundaries imply that there is some weaker commonality in the types of operations required.

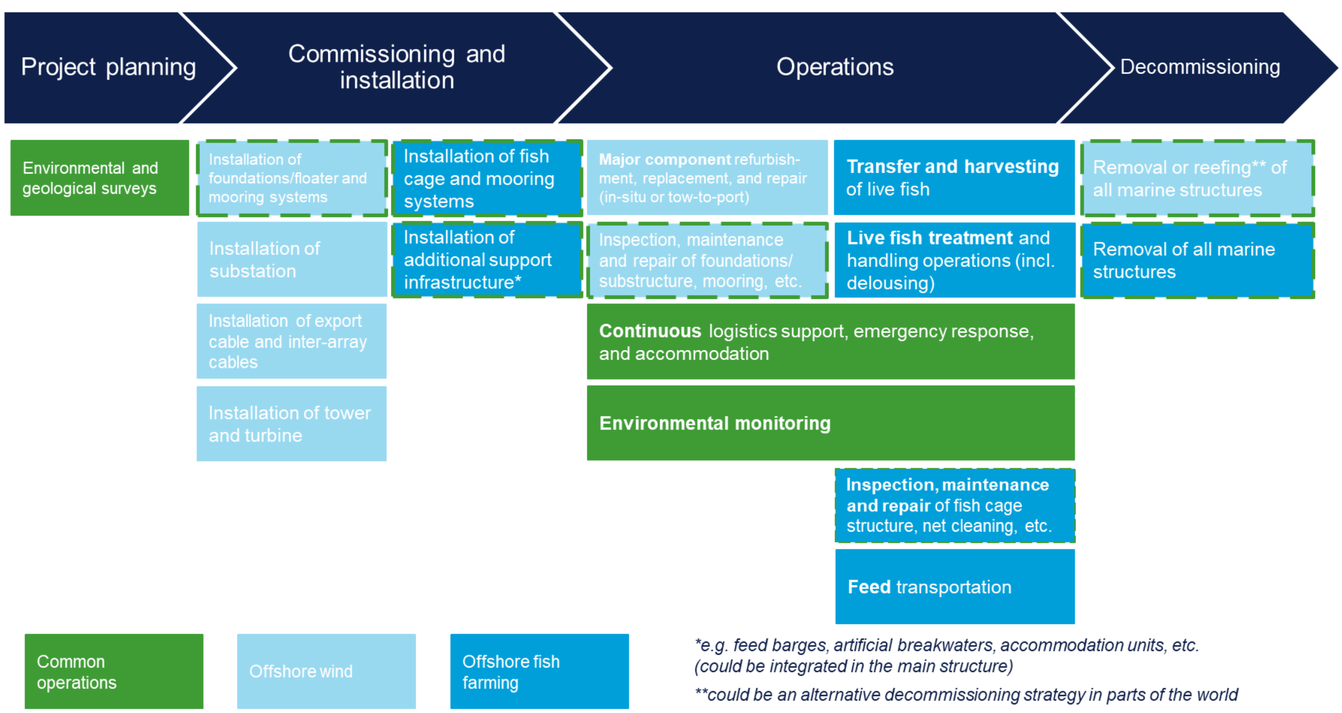

Figure 6: Lifecycle activities with main vessel operations reflected, for offshore wind and offshore fish farming.

From the lifecycle overview of key functions that need vessel support, it is clear to see that there are already some clear commonalities. We review the lifecycle phases, except decommissioning, and address common and distinct needs in offshore wind and offshore fish farming below. We then summarize the qualitative assessment of potential for multi-use synergies.

Project planning phase

During the project planning phase offshore wind makes use of both geophysical survey vessels and vessels for geotechnical surveys. Geophysical surveys make use of non-intrusive methods like multibeam echo soundings, sonars, and seismics to map the seafloor.

Geotechnical surveys are the more intrusive of the two and include sampling of rock and soil by methods like boreholes and cone penetration testing to understand specific seabed features and soil behavior under dynamic loading from wind, waves, and currents. Geotechnical survey vessels often have onboard laboratories for processing of the samples (The Crown Estate & ORE Catapult, 2019). To anchor larger offshore fish farm structures, many of the same methods will be required to verify the integrity of anchoring and mooring systems.

Environmental sampling of seabed (benthic) marine life is also becoming more important during project planning, as an understanding of ecological baselines becomes more important with ocean industries increasingly required to report on their biodiversity impacts (Pardo et al., 2023).

Commissioning and installation

During commissioning and installation, both offshore wind and aquaculture will require transportation of major equipment to the site, as well as anchoring. Bottom fixed offshore wind turbines need to be installed in multiple steps, with final assembly taking place on site. The installation of the tower and turbine itself (with nacelle and blades) is normally done by large wind farm turbine installation vessels (WTIVs) with large cranes having significant reach (+200 m above sea level) and capable of lifting 1500 tonnes or more. These vessels can also install the foundations unless these are lowered by use of heavy lift vessels.

Floating structures like large fish farms or floating wind foundations can be transported to site by towing or on the deck of semi-submersible heavy-lift vessels. Semi-submersible heavy-lift vessels have already been used for transportation of several high profile offshore fish farms, such as Nordlaks' Havfarm (Baird Maritime, 2020). New concepts for wind turbine installation are emerging, as floating offshore structures and larger turbines set new requirements to lifting capabilities (Zwaginga et al., 2021). When the wind farm is located close to shore, or the weather conditions are such that the technicians needed at the wind farm can be transported every day to/from a nearby port without getting seasick, crew transportation vessels (CTVs) are often used.

Commissioning support tasks in offshore wind are increasingly provided by commissioning service operation vessels (CSOVs). While SOVs typically provide support in the operations and maintenance phase of the lifecycle, CSOVs support the commissioning phase. CSOVs are often with larger capacity to accommodate people onboard, while many of the other capabilities are similar to the smaller SOVs. Helideck is one option you can find on both SOVs and CSOVs (but not a standard), while CSOVs are often outfitted with bigger cranes for offshore use. Since CSOVs can provide commissioning support, they are typically hired for shorter contract periods than SOVs., and may command much higher chartering rates. Both SOVs and CSOVs often work together with one or more daughter crafts or fast crew transport vessels (CTVs) to ensure faster mobilization of people to multiple turbines when this is required. With larger offshore wind farms, where rotor and turbine components increase in size, some developers are changing their O&M planning, so that CSOVs increasingly are engaged on long term contracts to meet the more complex maintenance needs. Notional design parameters for a typical SOV are contrasted with those of an CSOV in Table 3.

Table 3: Some key design parameters of SOVs

	SOV	CSOV
Length (incl **average**)	57-93 m **(80 m)**	80-108m (**90 m**)
Gross tonnage	2900-6800 GT	5500-7300 GT
Accommodation (People on Board - POB)	36-124 (**60** POB)	60-135 (**120 POB**)
Deck area	200-750 m^2	320-750 m^2 (one with 1000 m^2)
Gangway + Offshore crane	Motion compensated	Motion compensated
Fuel	Marine gas oil (MGO)+hybrid/battery + prepared for alternative fuel	MGO+hybrid/battery + prepared for alternative fuel

Anchor handling tug supply (AHTS) vessels commonly used during rig moves can contribute if there are towing operations, and during installation of mooring systems. AHTS vessels will likely be taking on role during the installation phase in both offshore wind and offshore fish farming. To some extent, offshore fish farms can be built to(be relatively easy to remove and for some concepts the primary maintenance strategy is to carry out repairs in port, potentially making AHTS day rates the driving factor in offshore aquaculture OPEX. Similarly, there may be opportunities for complex offshore support vessels to provide construction support, including lifting operations, as well as support to underwater inspection and repair services. These vessels will prioritize offshore O&G support work as long as the rates are higher in that market. One additional factor to consider for possible cross industry work is the limitations that may be imposed on the operators from investors or other important stakeholders, typically related to ESG (Environmental, Social, Governance)-aspects (e.g. some investors will not accept services to be delivered from the financed asset like an SOV to other industries than the renewable industry).

Other specialized offshore vessels at use in offshore wind operations includes cable-layers and subsea rock installation vessels. There could be some cable installation needs to connect offshore fish farms with nearby wind farms for powering. However, with a need for stable powering, such solutions will require storage to reduce intermittency challenges. Besides this, with a relatively low energy consumption in the first place, offshore fish farms will likely still be fueled by diesel.

Operations

During the operational phase, offshore wind and offshore fish farms share several needs. Both sectors will require inspection, maintenance, and repair operations, emergency preparedness, and accommodation for personnel. Additionally, continuous monitoring operations will likely be required for future operations to understand nature impacts.

Underwater inspection, maintenance, and repair tasks. Underwater inspection services will largely be performed by ROVs launched from service vessels through moonpool or over the side that inspect wind farm foundations, floating structures, fish farm nets, and mooring systems. Some diving support is also used both in established wind farm operations and in coastal aquaculture. In aquaculture, diving support operations are often carried out using smaller fast-moving vessels. With deeper waters, diving operations will potentially be reduced in favor of ROVs, as diving in deeper waters comes at higher risk and requires technically complex support systems found onboard offshore O&G diving support vessels.

O&M support, crew transfer, and accommodation. Operations and maintenance support to wind turbine components located above the foundations or floaters are normally done by technicians landed onto the turbines from either crew transfer vessels or from motion-compensated gangways onboard service operation vessels (Irawan et al., 2023; Lazakis & Khan, 2021). SOVs have quickly become the work horse of the offshore wind industry, as wind farms have grown and are located further from shore. Where crew transfer vessels, often catamarans, are used for transport of technicians to smaller wind farms close to shore, SOVs provide accommodation and a stable platform for safe crew transfer to turbines in rough weather, thereby increasing the size of weather windows for maintenance and repair (Irawan et al., 2023). With the space to carry spare parts and workshops to carry out smaller repair work, purpose-built SOVs have made it more challenging for PSVs repurposed from offshore oil and gas to compete in the offshore wind market (The Crown Estate & ORE Catapult, 2019), without first being retrofitted with additional accommodation space and W2W functionality.

SOV functionality will also be useful in the fish farming context. While the industry will want to move towards autonomy in offshore fish farms to reduce risk to crew, they will likely need to have personnel onboard often to manage the operation (e.g. managing feed distribution, inspecting structures, handling dead fish). A concept of operations where an SOV provides accommodation and safe transfer to wind farms and offshore fish farms that are located sufficiently close to each other, could result in shared, and thereby reduced, chartering costs. W2W functionality provided by actively motion-compensated gangways could be one example of a ship function from offshore wind that easily contributes to improved personnel safety in offshore fish farm operations.

On the other hand, there can only be a limited role for aquaculture service vessels in supporting wind farm operations. The types of services these vessels provide are often related to simple lifting operations, including net handling and cleaning.

Fish handling. Handling live fish requires a lot of specialized functionality that has no use in offshore wind. Figure 7 presents the key functions performed as part of the live fish logistics.

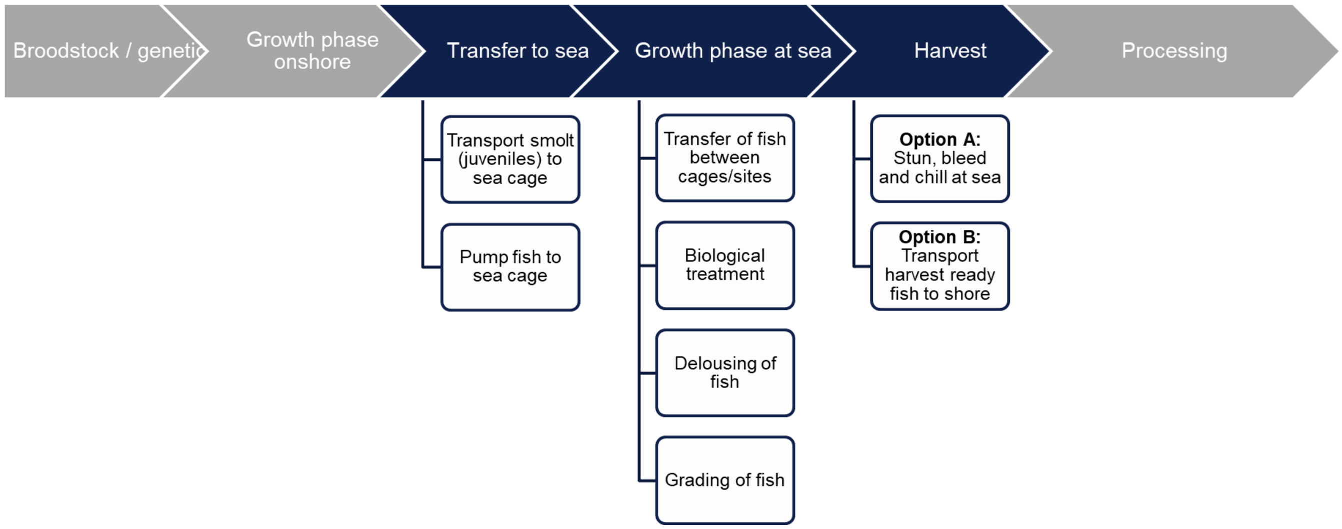

Figure 7: Salmon lifecycle with emphasis on key ship functions.

Well boats or live fish carriers play a key role in the transportation functions and are built around holding tanks designed to carry fish, with associated circulation systems to maintain good water quality. Importantly, well boat design considers biosecurity measures, to mitigate the risk of disease transfer between fish farm sites. Grading, delousing, and biological treatments are often also performed using well boats. In some cases, these functions are performed by specialized delousing vessels. Like in the offshore wind market, there have also been examples of PSVs retrofitted with delousing equipment for work in the aquaculture industry (AquaShip, 2021; Dixon, 2020).

Fish handling logistics could change because of larger distance to shore and more rough weather. With larger fish cages further from shore, newbuilt well boats have also become larger and more complex. More ships will likely be built with stun, bleed, and chill functionality to avoid detrimental fish health impacts from sloshing during transit from offshore cages to shore. Still, fish handling logistics will to little extent be affected by potential multi-use synergies.

Emergency response. Besides similarities in the need for accommodation for personnel, both offshore wind and offshore fish farming will need emergency preparedness. The emergency response needs of the sectors will only partially align, due to the presence of personnel working at sea. Beyond responding to incidents that could harm personnel, the emergency response system in aquaculture also needs to consider fish-related incidents. Compared to the use of emergency response and rescue vessels (ERRVs) in offshore oil and gas, the risk to personnel is smaller in both offshore wind and aquaculture.

Fish escape incidents, algal blooms, and disease outbreaks constitute key concerns in aquaculture that typically will be addressed using vessels with specialized fish handling capabilities (Slette et al., 2022). Disease outbreaks are often managed by removing dead fish and by slaughtering sick fish earlier than planned (Barrett et al., 2022).

Commonalities in mission requirements

We now turn to providing a summary, qualitative assessment of ship capabilities and commonalities in mission requirements. Table 4 summarizes vessel capabilities needed in offshore wind and offshore fish farming. Eight of the identified special ship types provide functionality that is interesting for both segments. The largest potential for exploiting synergies will be in the project planning and operational phases. In the commissioning and installation phases, highly specialized capabilities are needed on the offshore wind side, that do not lend themselves well to aquaculture.

Table 4: Ship types and use in marine operations in offshore wind and offshore fish farming. Ship types highlighted in italics score above 'Low' in technical feasibility for both offshore wind and fish farming.

Ship type	Lifecycle stage	Main functions	Offshore wind	Offshore fish farming
Geophysical survey vessels	*Project planning*	*Non-intrusive seafloor mapping, environmental monitoring*	*High*	*High*
Geotechnical survey vessels	*Project planning*	*Rock and sediment sampling, onboard processing, environmental sampling*	*High*	*High*
Wind turbine installation vessels	Commissioning and installation/ Decommissioning	Installation of wind turbines	High	Low
Heavy-lift vessels	*Commissioning and installation/ Decommissioning*	*Installation of substations, floating structures, turbine foundations*	*High*	*Medium*
Cable laying vessel	Commissioning and installation	Installation of inter-array cables inside wind farms, installation of export cables	High	Low
Subsea rock installation vessels	Commissioning and installation	Install scour protection for foundations and cables	High	None
Anchor handling, tug, supply vessels	*Commissioning and installation/ Operation/ Decommissioning*	*Towing operations, installation of mooring system*	*High*	*High*
Commissioning service operation vessel	*Commissioning and installation/Operation*	*Accommodation, walk-to-work (W2W) system, workshops, spare part storage, lifting operations, construction support, repair*	*High*	*Medium*
Offshore support vessels (O&G)	*Commissioning and installation/ Operation*	*Inspection, maintenance, and repair operations, lifting operations, diving support, ROV support*	*High*	*High*
Service operation vessel	*Operation*	*Accommodation, walk-to-work system, workshops, spare part storage, repair*	*High*	*Medium*
Delousing vessels	Operation	Biological treatments, removal of sea lice from fish	None	High
Well boat	Operation	Transport of live fish (smolts) to offshore fish farm; transport of live fish (mature) to harvest site on land; delousing operations	None	High
Slaughtering vessels	Operation	Onboard slaughtering facilities, cooling and freezing	None	High
Aquaculture service vessels	*Operation*	*Lifting operations, towing, (some) delousing operations, net cleaning*	*Medium*	*High*
Bulk carriers/multi-purpose vessels	Operation	Transport of fish feed, transport of frozen fish	None	High
Feed barges	Operation	Store and distribute fish feed (integrated in some offshore fish farm structures)	None	Medium

During project planning, the synergies mainly lie in about data and data sharing. By sharing data from previous surveys, impact assessments and seabed surveys could be fast-tracked for a second user of the same marine space.

In the operational phase of the lifecycle, multi-use synergies are present over a long period, making it potentially commercially interesting to take advantage of resource sharing schemes that is enabled by the fact that multiple users operate in the same area.

Estimate of potential savings

In the final part of this section, we provide a simple estimate of the power savings potential from multi-use synergies, considering the reduction in transit need if logistical demands can be coupled. We also comment briefly on potential fleet level impacts on capital expenditure.

A typical offshore support vessel spends close to 40% in transit, or around 3,000 hours per year (Lindstad et al., 2017). If we assume a similar pattern for special ships servicing the new offshore industries, and that half of the roundtrips are used to service both a wind farm and an offshore fish farm, then the transit time will be reduced by 25%. For simplicity, if we then assume that the same amount of time will be spent in transit at higher speeds, as these are likely missions with higher criticality, and therefore maintains some conservatism in the estimate of savings. If we then assume the average power requirement and specific fuel consumption for a variable speed engine with a specified operational mode, as suggested by Lindstad et al. (2017) and partially reproduced in Table 5, we observe fuel savings of around 5%, as the annual consumption reduces from almost 2,900 tonnes to just over 2,700 tonnes. This calculation assumes the use of diesel oil (for simplicity), and the actual savings potential will also depend on the dynamics of the future fuel mix (including new fuels) and the pricing of these alternative fuels. The effect of the reduced transit on costs might well be bigger, when taking into consideration the pricing of alternative fuels (DNV, 2023b).

Note that the share of time on dynamic positioning and for port loading operations increases when vessels are shared, meaning that there is an even greater potential for fuel saving, as batteries can play a key role during DP operations providing more flexible load. If offshore charging infrastructure is developed at wind farms, batteries may become an even more important part of the fuel mix of vessels serving offshore wind and could realize its potential to improving DP operations providing more flexible load (Lindstad et al., 2017; Holmefjord et al., 2020). Adding to this, we already discussed the role of the EU ETS in incentivizing shipping emission reductions (DNV, 2023b), and note that, all else kept constant, the carbon intensity of the fuel consumed will remain an important operational parameter in years to come.

Table 5: Example of change in operating profile and annual fuel consumption from shared offshore vessel capabilities.

Operational mode	**Original operational profile**		**Lower (75% of original) transit share of operational profile – due to co-location**		**Average power**	**Specific fuel consumption (variable engine speed)**	**Annual fuel consumption**	**Annual fuel consumption**
	Annual hours	**Share of time**	**Annual hours**	**Share of time**			**(original operating profile)**	**Lower transit share operating profile**
	Hours	**%**	**Hours**	**%**	**kW**	**g/kWh**	**Tonnes**	**Tonnes**
Dynamic positioning (DP)	*2400*	*27*	*2920*	*33*	*1600*	*210*	*806*	*981*
Standby	600	7	600	7	1500	205	185	185
Port	*2270*	*26*	*2500*	*29*	*336*	*265*	*135*	*149*
Transit ECO	*3000*	*34*	*2250*	*26*	*2300*	*200*	*1380*	*1035*
Transit 12 kn	400	5	400	5	3300	197	260	260
Transit 15 kn	90	1	90	1	6000	204	110	110
Total	8760	100	8760	100	-	-	2876	2720

Besides the effects on operational issues like emissions and operating costs, synergistic multi-use will also impact capital expenditure (CAPEX). For a single design case, the CAPEX will likely increase due to the need of catering to requirements for operations in several different market segments. Cost-related pitfalls of multi-functionality as pointed to by e.g. Gaspar et al. (2015) and Garcia et al. (2016) need to be avoided, and principles related to operational flexibility (Lindstad, et al., 2017; Rehn et al., 2019; Pettersen et al., 2020) adhered to, for this to remain a viable business case for ship owners. On the level of the support vessel sector as a whole, successful exploitation of synergistic multi-use logistics means that fewer vessels are needed to service a set of ocean assets. This means that less steel will be needed, further reducing the environmental footprint, and reducing CAPEX on the level of the whole industry. The same could hold true for the fleet design problem facing those ship owners that seek to take advantage of synergistic multi-use logistics.

OPPORTUNITIES AND BARRIERS

Sharing resources among several actors in the ocean space can be an opportunity to reduce costs, emissions, and to create a culture of collaboration across sectors that otherwise would compete for access to ocean area. We have established where the potential for sharing and synergistic multi-use lies, by identifying ship types that provide functions that can be useful in a multi-use setting. We now turn to discussing what key opportunities and barriers that exist to realizing this potential.

Opportunities

Reducing fuel consumption and operating costs by sharing logistics
From the perspective of an offshore wind farm or an offshore fish farm, the costs associated with chartering in special ships for the operational phase will constitute a relatively small share of the lifecycle cost. In offshore wind, operating costs overall constitute 25-30% of the lifecycle cost, of which a relatively small part will be vessel chartering during the operational phase. Still, sharing can constitute an interesting cost cutting measure, when seen along with developments like the introduction of carbon pricing. If shared logistics, as indicated in Table 5, in some cases can realize a 5% fuel saving, this is an opportunity that should be welcomed by ship owners and charterers.

The previously referred *NEXUS* project also provided some new insights into the feasibility of fully electrical operation of vessels at a wind farm (Holmefjord et al., 2020). Such operations are feasible provided sufficient infrastructure for charging is in place together with sufficient onboard energy storage (e.g. batteries). The opportunity to use renewable energy directly from a wind farm to charge offshore vessels is now being explored by several (Stillstrom, 2023; Memija, 2023), while ship designers are working on conceptual designs where space for sufficient energy storage and charging technology is integrated in close dialogue with owners and regulatory bodies (flag authorities and classification societies as DNV), see e.g. The Naval Architect (2024).

Reducing conflict potential through co-existence and multi-use
Besides the purely technical-economical argument above, the reduction of conflict potential that can be enabled by multi-use is substantial. From the discourse on the impact of offshore wind on other stakeholders, there is still a clear tendency to focus on the conflicts, which could hamper the “social license to operate” that any sector will be dependent on to some extent. This is most clearly seen in the relationship between offshore wind and the fisheries. Again, focusing on the potential synergies of this situation, rather than the trade-offs in what is quickly perceived as a zero-sum game, can create an atmosphere of collaboration between stakeholders.

The clearest marine design dimension to this question is the use of vessel capabilities for new types of operations. In the spatial relationship between offshore wind and the fisheries, compensation schemes to fisheries due to their exclusion from certain areas have been discussed. From other offshore sectors like oil and gas, there are examples of fishing vessels playing a key role in supporting emergency response operations, as exemplified by the Vessels of Opportunity-scheme deployed to participate in oil spill clean-up operations after the Deepwater Horizon accident (Pettersen et al., 2020). Identification of *latent capabilities* that were not intentionally designed for, can make fishing vessels useful in offshore wind operations or offshore aquaculture and could be a path to explore further.

Novel ways of meeting offshore wind tendering requirements
Co-existence is also finding its way into tendering requirements for offshore wind. In some cases, this could take the form of binary conditions, e.g. “it is required that the applicant has a co-existence plan”. In other cases, non-price criteria are being shaped to award offshore wind tenders based on more quality parameters, including the design of specific measures that will ensure successful collaboration with other ocean stakeholders over the field lifecycle. This can be measures such as nature restoration by re-introduction of lost habitats (Pardo et al., 2024), or farming of blue mussels and kelp to extract excess nutrients from the sea, thereby improving water quality and/or providing human food.

Taking the arguments made in this paper further, these overarching government tender requirements could also percolate down to the specifications of chartering arrangements that ship owners will need to comply with to win contracts. For instance, could the future see chartering contracts being more explicit on the vessel’s ability to also provide support to a co-located aquaculture operation?

Barriers

Technical barriers

Technical barriers to realizing synergistic multi-use related to the functionality of specific solutions. If there are significant amounts of mission-related systems onboard which are useful in the context of offshore wind, but without applications in the other sector to service, e.g. offshore aquaculture, then there is limited potential. The discussions in earlier parts of this paper largely screened for vessel types that can have applications in several sectors and sought to answer to what extent functionality from ship segments serving offshore wind, e.g. SOVs, could service offshore aquaculture. If similar solutions are sought out, for instance heavy-compensated gangways to improve operability and personnel safety, then the design features on the side of the offshore fish farm should be introduced to ease the compatibility with SOVs. For instance, the DNV class rules for floating fish farm installations lists "offshore gangways" as a relevant optional class notation (DNV, 2022a).

Operational barriers

Multi-use concepts have been observed to cause certain ambiguity in risk ownership, causing some authorities to impose operational restrictions for safety reasons (van den Burg et al, 2020). For instance, safety zones are one example where other activities are effectively banned from the vicinity of another. These might have good reasons, as in the case of oil and gas installations, but might be too strict for other types of offshore platforms.

Furthermore, if multi-use concepts are not restricted by e.g. safety zone issues, there still might be the need for development of appropriate operational procedures to allow for new types of vessel-structure interactions, for instance when an SOV services an offshore fish farm. In such cases, the successful operation of vessels in a multi-use logistics context also becomes a function of organizational factors like crew competence, training, and experience.

Finally, mission criticality considerations will also play a role as an operational barrier, seeing that an unplanned repair operation at the wind farm may need to take priority over a planned mission to service the offshore fish farm. If so, what should dictate when an unplanned mission at production system *A* should take priority over a planned mission at the co-located production system *B*? And who should pay?

Commercial barriers

The question posed above illustrates the core limitation to realizing synergistic multi-use logistics from the commercial point-of-view. Chartering arrangements need to reflect the co-use of vessels for both purposes and determine how the risks associated with the operations should be spread. The ease of creating a joint chartering arrangement could come down to factors such as organizational structure of the offshore wind/offshore fish farming operator. For instance, does common ownership over both production systems imply that establishing a joint chartering arrangement is easier? Would horizontally integrated companies that operate across several blue economy sectors like renewables and seafood more easily see the potential for multi-use synergies, and be more likely to realize them?

A second commercial barrier is related to the cost of managing the complexity of two disjoint operations. We observed earlier in the paper that the share of vessel-related costs during the operational phase of a wind farm (or a fish farm for that matter) is only a small share of the total operating costs. Hence, the increase in transaction costs related to managing a much more complex chartering arrangement may not be worth it, from the point of view of the charterer. Also on the supply side, a similar problem might exist, particularly in good times, when rates are high. Who would then bother taking on a more complex arrangement that may not pay a sufficient premium?

CONCLUSION

In this paper, we have introduced the concept of multi-use of marine space to the ship design audience. Where ideas of multi-use and co-existence have emerged in the marine spatial planning research community, there has so far been little work on understanding the roles special ships can take in a Blue Economy shaped by the need for sharing of maritime resources. We have provided an overview of some key drivers for marine multi-use and sharing of vessels in this setting and provided a qualitative assessment of key operations performed in offshore wind and aquaculture, aiming to identify areas for synergistic multi-use.

We have also provided insight on the key pros and cons of moving towards synergistic multi-use, pointing to drivers like reduced costs and emissions, as well as reducing conflict levels. The need for emission reductions and stakeholder collaboration appear to be the strongest drivers. On the side of barriers, chartering needs to take into consideration longer response times to missions of high criticality, and to consider how risks should be allocated.

While there are clear benefits, we ended the discussion with a set of more cautious remarks about the barriers. Further research could take a closer look at the shipping economics at play, the trade-offs, and the conditions under which synergistic multi-use would make sense. Assessments of multi-purpose platforms so far, at best, provide a mixed bag of results and with the previous experience from multi-functionality in offshore support vessels, there is reason to approach the concept with cost and emission reductions in mind first.

CONTRIBUTION STATEMENT

Sigurd S Pettersen: Conceptualization; writing – original draft; writing – review and editing. **Arnstein Eknes:** Conceptualization; writing – review and editing.

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