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RESEARCH PAPER

The Financial Feasibility of Farming Blue Mussels Offshore Using the Smart Farm Approach: European Evidence

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Abstract

This paper analyses the financial feasibility of a mussel farm that employs the Smart Farm approach with reinforced equipment in the offshore Dutch North Sea. The literature review suggests favourable conditions for this farm given past Smart Farm applications, existing offshore mussel farms, environmental impact considerations, offshore mussel health, and Dutch regulatory clarity. The study methodology section explains the utilization of the discounted cash flow (DCF) analysis model and the technological, farm size, location, mussel seed collection, cost, and production assumptions. This farm would require an initial capital expenditure of €1,695,350 and would produce 300 tonnes per annum (tpa), which would progressively increase to 700 tpa based on additional mussel lines and mature farming practices. This study found an Internal Rate of Return (IRR) of 19.78% and a Net Present Value (NPV) of €3,479,178 over 25 years. This IRR is higher than rates projected by comparable studies. It is attributed to the strong technological maturity, mobility, scalability, mechanization, and production offered by the Smart Farm. Through pursuing this farm and similar mussel farming projects, investors can help advance humanity across domains including employment, sustainability, ocean decarbonization, the ocean economy, nutrition science, maritime engineering, aquaculture, world food supply, and upward mobility.

Introduction

The global aquaculture industry brims with unrealized potential. McNevin (2021) noted that although aquaculture is one of the fastest growing forms of food production globally, its ability to scale significantly and reduce global poverty is not being realized because of risk aversion and overly conservative business practices. At the same time, the vast spaces of the world's open seas represent a largely unleveraged opportunity for aquaculture scalability and the benefits thereof. While horizon-spanning offshore aquaculture operations are not in the foreseeable future, investors would be remiss to ignore the benefits that attend smaller offshore mussel farms that could potentially serve as precursors of said operations. Offshore mussel operations currently exist in France and Italy (Buck et al., 2017), the United Kingdom (Offshore Shellfish, 2024), New Zealand (Open Ocean Whakatohea Mussels, 2024), and California (Catalina Sea Ranch, 2024). Van der Schatte et al. (2020) have documented the far-reaching ecological benefits of bivalves. These include that farmed bivalves remove 6,000 tonnes of phosphorous and 49,000 tonnes of nitrogen from the oceans annually, which is worth potentially USD 1.2 billion (p. 3). Bivalves also provide habitats for other marine life through their sediment (p. 6). Bivalve shells can also be used for poultry grit, fertilizer, lime, and construction materials (p. 8). Bivalves also increase seabed roughness (p. 5) and potentially play a role in carbon sequestration (p. 12). Further, zoologist David Willer is quoted by Lovell (2024) as saying that bivalve aquaculture has a lower environmental footprint than many crops in terms of land, freshwater use, and greenhouse gas emissions.

While finding that shellfish culture can impact phytoplankton community structure and benthic community, Tan et al. (2024) acknowledged that the environmental impact of shellfish culture has typically been beneficial. Mussel farming's environmental impact concerns have most typically been associated with situation-specific factors such as limited water circulation and oxygenation (European Commission, 2017) and mussel dredging practices (Brohmall et al., 2022).

Mussel farming also significantly contributes to global food security. Azra et al. (2021) conducted an assessment on the contribution of shellfish to global food security, concluding that its role is 'important' (p.1). The increase in annual global mussel revenue from \$3.56 billion to \$104.55 billion between 1985 and 2018 (p.2-3) indicates that not only is global mussel production scalability achievable, but it has already been achieved and has potential for further growth. Gentry et al. (2017) discovered that there are 1,500,000 square kilometres of ocean space globally suitable for offshore mussel farming. Willer, quoted by Lovell (2024), suggests that utilizing just 1% of the available shellfish farming space would generate enough shellfish to meet the protein demands of over one billion people.

The nutritional benefits of mussels are also not to be ignored. WebMD (2023) notes that mussels are a high-quality protein that contain many vitamins and minerals, including iron, Vitamin A, Vitamin C, and calcium. The Shellfish Association of Great Britain (2024) also notes that mussels are an excellent source of Vitamin B12, folic acid, zinc, selenium, iodine, and Omega-3, while being low in fat, saturated fat, and sugars (p. 1-2). Yaghubi et al. (2021) also reported that mussels offer benefits for heart health.

The intersection between the above documented benefits of mussels and the 17 sustainable development goals of the United Nations (2024) is also highly noteworthy. Sustainable Development Goals 1, 2, 3, 8, 12, and particularly Goal 14 - addressing No Poverty, Zero Hunger, Good Health and Well-Being, Decent Work and Economic Growth, Responsible Consumption and Production, and Life Below Water - can foreseeably experience meaningful advancement through the proliferation of offshore mussel farms worldwide.

In addition to these benefits, investors should consider emerging developments in the North Sea. The recently completed SPACE@SEA project successfully devised a technologically and financially feasible design concept for multi-use platforms in both the Mediterranean and the Dutch North Sea. The success of this project highlights the emerging possibilities for future sustainable ocean development, including those achievable through mussel farming.

Considering these factors, this study analyses the financial feasibility of an offshore mussel farm using the Smart Farm approach in the Dutch North Sea. Smart Farm (2024a) notes that the Smart system has a highly mechanized process that eliminates the safety concerns and extensive manual labour demands associated with conventional mussel rope culture farming. In the Smart process, all husbandry and harvesting is performed on site underwater by a large boat called the SmartCat. The harvesting process allows for a harvest of 30 tonnes per hour. The system is resilient in that it can be installed and remain in place for 25 years. Further, the system possesses inherent qualities for mussel seed collection, reducing additional labour needs. Smart Farm (2024b) further documents that the husbandry and harvesting machine on the SmartCat uses adjustable brushes near the mussels, facilitating both mechanized cleaning and harvesting. This enhances the overall mechanization of the farm.

A look at other types of mussel farming and Dutch mussel industry production outcomes heavily underscores the significantly lower labour inputs and higher mussel production offered by the Smart Farm. National Oceanic and Atmospheric Association (NOAA, 2024) documents that bottom and raft culture mussel farming is "hard work, muddy, and messy." The Mussel Industry Council of Prince Edward Island (2024) notes how the longline system used by Prince Edward Island farmers requires hand stripping of mussel spat from ropes on which they are grown and hand tying of mussel socks to long lines. The Food and Agricultural Organization of the United Nations (FAO, 2024a) documents the current aggregate shellfish production in the Netherlands to be 50,000 to 60,000 tonnes of mussels per annum (tpa) and 3,250 tpa of oysters, managed by 275 persons. In contrast to this, a Smart Farm depicted by Van Deurs et al. (2013) required only three full time employees and was projected to yield approximately 20,000 tonnes per season (p. 19,24).

The academic literature also highlights that the Netherlands has significant aquaculture innovation expertise that can be exported globally (European Commission, 2024) while the need for highly mechanized mussel farming in Europe is also stressed. Mussel farming equipped with mechanized handling could facilitate large scale European expansion (Seafish, 2024, para. 10). FAO (2024b) documents that automatic equipment optimizes profitability (p.5). The distressed Italian mussel farming sector needs structural change in part through investing in automating machinery and new technologies (Tudini & Forgione, 2024, p.71). Given these considerations, it is evident that a Dutch Smart Farm could potentially realize, leverage, and accelerate existing Dutch aquaculture innovation resources in a manner that is well matched with European mussel aquaculture mechanization needs.

Literature Review

This section discusses global mussel market, Project Edulis, and Offshore Shellfish outcomes together with considerations specific to wind farms, proposed multi-use platforms, Smart Farm technology, environmental impact and toxicity. Considerations related to Dutch regulations, the Dutch mussel industry, and global food security implications concludes.

The global mussel market was valued at USD 3.41 billion in 2023 and is expected to experience a compounded annual growth rate of 4.3% between 2024 and 2032 (Global Market Insights, 2024). Aggregate European mussel production was 431,000 tonnes in 2022, with imports playing a strong role in bridging European supply and demand (Riecken, 2024). Weaknesses of the European industry include low mussel prices, mussel industry atomization, and nearshore spatial and permitting limitations. Strengths include that it has a strong domestic market, a low environmental impact, and significant export potential through processed mussel products (Avdelis et al., 2021, p.96-99).

Project Edulis yielded recent findings that inform the financial and technical feasibility of offshore mussel farming. Representing eight academic, business, and research partners, this two year pilot project experimented with integrating mussel farming into wind farms 30 to 50 km in the offshore Belgian North Sea (Flanders Research Institute for Agriculture, Fisheries, and Food, 2020, p.1). Buck et al. (2010) and Bartelings et al. (2014) had much earlier projected positive investor returns for commercial scale projects of this type. Van Den Berg et al. (2017) had found that similar commercial scale Dutch farms could yield a positive IRR and NPV. They included a sensitivity analysis that considered possible variations in capital expenditure, operating expenditure, output, and revenues, which supported their findings of robust profitability (p.10). For its part, Project Edulis yielded 10 kg per meter of mussel line, which compared well to Irish and nearshore Dutch yields. North Sea turbidity directly translated to no major differences in mussel yield throughout the water column. However, a business case was not found for commercial scale projects of this specific type. Further financial feasibility research on the effects of scale, the optimization of maintenance operations at sea, and improving the harvesting and husbandry process were highlighted as critical to the longterm financial outlook of this specific approach (Flanders Research Institute for Agriculture, Fisheries and Food, 2020, p. 1-3). The immediate lack of business outlook was strongly attributed to distance from the coast and limitations inherent to wind platforms. The need for advanced technology relating to maintenance, safety, and strength was also critically stressed (Flanders Research Institute for Agriculture, Fisheries, and Food, 2024).

An examination of the outcomes of Offshore Shellfish yields data highly favourable to an offshore mussel business case, with annual mussel yields of 850 tonnes (Sense About Science, 2024) and projected future annual yields of 10,000 tonnes when their farm is fully scaled. On a full harvest day, their crew of eight to ten people will harvest approximately 44 tonnes of mussels from their longlines four to ten kilometers in the offshore English Channel (Aquaculture Stewardship Council, 2024).

The academic literature on multi-use platforms in the Dutch North Sea offers promising possibilities relating to offshore mussel farming. After comprehensively analysing the profitability of an energy, transport, aquaculture, logistics, and living hub on offshore platforms, Ahrouch and Breuls (2020) concluded that the creation of modular islands on both the North and Mediterranean Seas could be 'a costly, yet beneficial solution' (p. 6). Jak et al. (2020) noted that a mussel farm making partial use of four floating offshore North Sea modules could yield an IRR of 7.4% and an annual income of 247 million Euros. They also noted that their business case could encourage mussel farmers to move operations offshore (p. 5, 21). Jansen et al. (2016) found that mussel farming on Dutch offshore multi-use platforms offers the most biological, technical, and commercial potential compared to seaweed and finfish farming (p. 740). They noted a scarcity of economic feasibility studies related to mussel farms that utilize offshore platforms (p. 744) but found that mussel farms integrated into offshore wind farm platforms can be profitable (p. 745).

Regarding the academic literature on SMART Farm, the literature suggests that the SMART Farm is a mature, high yield, and advanced technology approach to mussel farming. In its earlier phases, however, there were peripheral challenges with two of its applications that appear to have since been overcome. Merc Consultants (2007) noted disappointing results in a Smart Farm application in Ireland. They did note that the problem (at the time) was with the mooring system, and that Smart Farm was coordinating closely with the relevant farm to remedy the problem (p.71). Smart Farm itself (B. Aspoy, Smart Farm, Microsoft Teams communication, July 2, 2020) has also communicated that there was a misapplication of their farm in this instance. Minnhagen et al. (2019) provided a report of a mussel farm in Musholm, Denmark that demonstrated that it can sometimes be of paramount importance to utilize an eider duck fence to avoid extensive duck predation (p. 10). Other research has yielded much more positive results. Van Deurs et al (2013) completed a financial feasibility study on the SMART mussel farm system in Denmark and projected a 25% IRR and a Net Present Value (NPV) of 19.8 million Euros (p. 11). They also noted this farm could produce 20,000 tonnes of mussels each year, and included an eider duck fence in the costs of the study to ensure no duck predation would occur (p. 10, 23). Van Deurs (2013) also documented that the strengths of the Smart Farm are that it is a recommended solution for harsh natural conditions and for reducing labour costs. While its installation costs are relatively high, the low associated labour costs have a positive effect on the production cost (p. 4). To provide further confirmation of the production capabilities of its technology, Smart Farm connected us to one of their customers. This customer confirmed that they use the Smart Farm to generate between 10 to 15 tonnes per unit of 100 meters per harvest cycle (Smart Farm customer, personal email, February 4, 2021). A blue mussel harvest cycle is 18 months (Jansen et al., 2016).

The academic literature supports employing an offshore approach when environmental impact studies are considered. Negative environmental impacts related to low water circulation (Baltic Blue Growth Project, 2019) or exceeding the ecological carrying capacity of the environment (Maar et al. 2023) are acknowledged. Simultaneously a broad array of environmental benefits such as reducing eutrophication are broadly documented (Baltic Blue Growth Project, 2019; Maar et al., 2023; European Commission, 2017). An exhaustive explanation of these benefits is outside the scope of this paper and has been provided elsewhere (McLeod & McLeod, 2019). A study involving the company Offshore Mussels in the English Channel found 'some evidence' that this mussel operation had helped to contribute to the restoration of the previously degraded sea bed (Bridger et al., 2022). An offshore approach also negates serious concerns associated with mussel dredging. The mussel farming sector of the Netherlands currently depends heavily on dredging to generate mussel seed (FAO, 2024a). NOAA (2011) references more than a hundred studies documenting that mussel dredging is connected to a broad array of environmental impact concerns including higher sedimentation, turbidity, sediment plumes, creation of trenches and dredge tracks, changes to sediment composition, disruption of sedimentation surface, damage and mortality to living organisms (inclusive of shellfish), and habitat impacts (p.12-22).

The academic literature on the presence of pharmaceuticals in coastal mussel populations further supports an offshore approach. Pavon et al. (2022) found a high presence of antibiotics and heavy metals in a Chilean region were likely creating greater degrees of genetically fueled antibiotic resistance in farmed shellfish. The authors suggested that accumulated mussel antibiotic resistance potentially could be transmitted to humans through the process of horizontal gene transfer (p.13). A study completed by Zacharias et al. (2021) on the Rhine River found antibiotic resistant bacteria in the mussels studied, although no multi-drug resistant bacteria was found. The findings of this study, while limited in their implications for saltwater mussel farming, are still suggestive in that a presence of antibiotic contamination in the Rhine River sufficient to create antibiotic resistant bacteria in Rhine mussels may suggest similar possibilities in the neighbouring Dutch coastal North Sea. Other studies have yielded results that are more favourable for both coastal and offshore mussel aquaculture. Chiesa et al. (2018) examined 50 mussel and clam samples from different FAO marine zones and found a negligible presence of antibiotics. Barralla et al. (2021) reviewed fourteen studies completed in Italy, Spain, Portugal, China, Singapore, California, and Brazil, and found that with the exception of tetracycline, which was found to be at a high concentration in the North Adriatic Sea, all antibiotic residues in the bivalves studied were under the limits set by the relevant authorities.

A similar analysis of the presence of heavy metals and other toxic compounds in coastal mussel populations lends additional credence to an offshore approach. Skjeggestad (2023) found that the Kristiansandfjord in Southern Norway had sediment contamination concentrations leading to 'very poor' environmental conditions. Skjeggestad further found most blue mussel stations in the fjord had 'not good' chemical status. Glorius et al. (2014) analysed mussel samples from eight locations in the intertidal Dutch Wadden Sea over two years. Environmental and consumption regulatory standards were met as regards toxic metals. Microbiological regulatory standards were met provided that customers did not consume oysters raw. However, a presence of polychlorinated biphenyl and dichloordifenyltrichloorethaan (both toxic chemical compounds) was found. Other research has found more favourable results for coastal operations. Bajc and Kirbis (2019) studied mussels from three Slovenian locations in the Adriatic Sea and found that the mussels met European Commission standards for human consumption. Gomez-Delgado et al. (2023) analysed mussels from one location in Western Norway over two years and found that the concentrations of toxic elements was within European regulatory parameters. Azizi et al. (2020) found that mussels sampled from the proximity of Al Hoceima, Morrocco presented no health hazards to customers. This was also found by Novakov et al. (2021) in reference to the conformity of Serbian mussels to European consumption standards.

An analysis of research completed with other species augments the favourability of an offshore approach. Significant blood chemistry differences in goldfish and mullet sourced from differing environments has been attributed to respective environmental flow characteristics (Parrino et al., 2018). Bioaccumulation of metals has been found in Mediterranean mussel and grooved carpet shell in low flow environments (Parrino et al., 2021). Bruno et al. (2024) found that the same species in Lake Faro in Italy were not at risk of toxic metal contamination and that pollutant levels represented no consumer concerns based on regulatory parameters. Given the divergent yet concerning toxicity findings in low flow environments, an offshore support is considered further supported.

Given the finding of strong academic support for an offshore approach across several research domains, an ensuing question naturally arises as to the degree of regulatory support that could be expected from the Government of the Netherlands. The Government of the Netherlands is directly encouraging of offshore mussel aquaculture, particularly in coordination with other economic sectors. In the National Strategic Plan for Aquaculture (2015), they suggest that the design concept developed by Space@Sea represents an opportunity for the mussel industry, as there is increasing interest in it for aquaculture use (p.15). The Ministry of Infrastructure and the Environment (2014) also has encouraged offshore mussel farming to coordinate with other offshore sectors (p. 64). The Dutch government has encouraged aquaculture in offshore wind and / or multi-use sites in the Policy Note North Sea 2009-2015 and the Integral Management Plan for the North Sea 2015 (Bartelings et al., 2014, p. 13).

The precise documents needed for an offshore mussel farm to begin operations do not appear to have been previously outlined in the academic literature. However, the Ministry of Agriculture, Nature, and Food Quality in the Netherlands (2021) communicated to us that a public license under the Fisheries Act, a location lease from their ministry, a public permit under the Nature Conservation Act, and a public permit under the Water Act of the Ministry of Infrastructure and Water Management would most likely be required. The ministry indicated that the costs for the second and fourth of these documents are unknown (presumably since offshore permits have never been fully realized). The first and third, they estimated, would be approximately several hundred Euros and anywhere from approximately a few hundred Euros to a few thousand, respectively (A. Kouwenhoven, Ministry of Agriculture, Nature, and Food Quality, personal email, April 13, 2021).

An offshore mussel farm also is beneficial to the aggregate mussel industry in the Netherlands. The Food and Agriculture Organization of the United Nations (2024c, hereafter FAO) notes that since 1987 there have been no new licenses granted in Holland for farming mussels. This is highly attributable to limited nearshore space. Jansen et al. (2016) indicate that space is simply too limited owing to competing stakeholders (p. 735). In contradistinction to FAO, however, Jansen et al. document that the Dutch government provided temporary licenses for offshore mussel farming in 2011, although these licenses were not used (p. 747).

A final question remains as to how the academic literature depicts the contribution of mussel farming to global food security. Costello et al. (2020) specifically note that bivalve mariculture currently accounts for 5% of global seafood. By 2050 it is projected to grow to 6%. In a scenario where demand might become extreme, it is projected to grow to 27%, provided shellfish aquaculture policy reform occurs. In a similar scenario where all seafood types are treated as interchangeable, shellfish could account for 34% of global future seafood production. The authors conclude that shellfish can contribute 'substantially' to global food security as they have relatively low retail costs and relative to finfish have lower production costs. They further document that by primarily expanding mariculture the oceans could reasonably provide six times more seafood than they do presently (p. 99). Azra et al. (2021) found that a critical issue to realizing shellfish potential is reducing production costs to increase affordability. They note that shellfish aquaculture will need to be intensified in upcoming decades to meet global demand in a cost-effective manner. The same authors found that recent increased global demand for shellfish is attributable in part to the nutritional and health benefits of mussels. They suggest that demand-driven production should apply optimal and affordable pricing to be inclusive of low-income customers. They quote Teneva et al. (2018) to highlight that food security is not related only to adequate production volumes but to affordability to the general population (p.5). This finding is echoed by Howell (2021), who stated that shellfish farming could serve as a 'core' component to global food security in upcoming decades, but that its potential may be limited because of farming expertise deficiencies and increasing consumer costs. These findings evince that mussel farming can very significantly contribute to future global food security, although obstacles would need to be overcome in the process. Given the potential mussels offer to global food security, given the success of similar operations such as Offshore Shellfish, given that offshore mussels are environmentally and nutritionally advantageous, given that new nearshore Dutch mussel farms are regulatorily infeasible, and given the Dutch government's demonstrated record of regulatory openness to offshore mussel farming, the present appears to be an opportune time for offshore mussel farming in the Dutch North Sea.

Materials and Methods

In this section the hypothesis, process, basic assumptions, and financial model of this study are presented. The hypothesis of this study is that a 25 year mussel farm that employs Smart Farm equipment in the offshore Dutch North Sea can be profitable, mechanized, productive, advanced technology, and scalable in a way that is beneficial to global food security, the natural environment, and human nutrition and health. Accordingly, the objectives of this study are to assess the following:

- The financial feasibility of this 25 year proposed farm, including Weighted Annual Cost of Capital (WACC), Earnings before Interest and Taxes (EBIT), Internal Rate of Return (IRR), and Net Present Value (NPV);
- Past profitability projections from other offshore mussel farms, past Smart Farm performance, regulatory and environmental feasibility, and offshore mussel health in view of the academic literature. In so doing, the presence or absence of conditions necessary for the implementation of this farm will be established;
- The contribution of this farm to global food security in view of the academic literature and the profitability, mechanization, advanced technology, scalability, and high-volume production of this farm.

Study Process

We began this study by approaching Smart Farm and requesting to complete a study with them. Smart Farm agreed and provided consultation throughout accordingly. We completed this study remotely without in person meetings and instead communicated using phone calls, internet conferencing, and emails. After reviewing the literature, we elucidated study assumptions including ideal farm location, mussel seed collection, eider duck predation, reinforced technology needs, and farm size. Following this, we identified and populated the cost categories, mussel production expectations, and farm timespan. We obtained some cost data points directly from Smart Farm pricing data (i.e.: SmartCat costs) and Smart Farm expertise (i.e.: average small boat cost). We also directly requested the Government of the Netherlands, the Yerseke Mussel Auction, Global Aquaculture Insurance Consortium, and other parties to provide various data points. Each party was well qualified to provide respective data, and included the secretary of PO Mosselcultuur, both cofounders of Smart Farm, an underwriter at Global Aquaculture Insurance Consortium, and representatives from Statistics Netherlands. Public data available from the Netherlands was also used to generate information such as financing costs and licensing data. After we populated all the relevant categories (data, assumption, production expectations, and farm timespan), the financial model emerged. We subsequently completed profit calculations to generate the WACC, EBIT, NPV, and IRR.

Basic Assumptions

The basic assumptions of this study consist of the following:

- An offshore mussel farm in the Dutch North Sea;
- 25 mussel lines employed at the beginning of operations, each of which would reliably produce at least 12 tonnes of mussels each 18 month farming cycle;
- A gradual increase to 56 mussel lines at the 20 year mark;
- Access to and employment of highly mechanized Smart Farm technology, by which mussels are cultivated and harvested efficiently with no direct hand labour;
- Suitable environmental conditions to support mussel production;
- A supportive regulatory environment for mussel farming in the Netherlands;
- Market factors such as mussel demand and selling price in domestic and international markets.

Location Analysis

Regarding the ideal location for this farm there are several guiding factors that we considered. FAO (2024b) notes that presently all mussels farmed in the Netherlands are sold at the Yerseke auction. Given this, proximity to Yerseke is ideal but not critical. The permitting process also needs to consider that each Smart Farm unit is 137 meters long. The scale of the proposed farm at inception is 25 units but increases to 56 within 20 years. However, given the Smart Farm's strength of scalability, extensive additional space may be important to leverage initial profit successes into future growth. Other Smart Farm applications such as the Smart Farm operation proposed by Van Deurs et al. (2013) are much larger and had 800 units, required only three full time employees, yielded approximately 20,000 tonnes per season, and could make use of different plots (p. 19,24). Given this, requesting a permit for a sizable area may be in order. We also noted that Ahrouch and Breuls (2020) project that the North Sea multi-use platform(s) depicted by the Space@Sea project will be in Dutch waters offshore from the Port of Antwerp (p.9), which is also highly relevant.

While all these considerations taken together create an ideal general area for the proposed mussel farm, other considerations suggest that this ideal location may not necessarily be within reach. The Government Gazette of the Kingdom of the Netherlands (2011) has identified the complicated space considerations that relate to wind farms, shipping lanes, defence needs, and other spatial considerations; a map they provide of offshore North Sea operations makes these considerations especially apparent (p.3). Given these considerations, it is outside the scope of this paper to predict the exact location that would be assigned to this farm.

Regarding the relationship developed with business operations on future North Sea platforms, we chose to propose a farm that can potentially have a symbiotic relationship with said future platforms, but which also can exist in a manner fully independent of them. It is important to underscore that while a symbiotic relationship is naturally to be strived towards, there does not appear to be any scenario where our proposed farm would be critically dependent on it. The farm and the multi-use platforms could have this symbiotic relationship in two ways. Were the mussel processing plant proposed by Jak et al. (2020, p.5) to be developed on these platforms, this plant could be used in lieu of or in addition to that offered by the Yerseke Mussel Auction to obtain a more competitive price. In turn, this could naturally increase the economic viability of these platforms. Additionally, this proposed farm could have a symbiotic relationship with these floating multi-use platforms if permitting was to place this farm at some distance from a coastal harbour. Given the rough nature of the Dutch North Sea and that the proposed North Sea platforms are expected to be large (housing up to 1353 people, [Ahrouch & Breuls, 2020, p.19]), the multi-use platforms could potentially offer additional options for emergency health care, boat harbouring, and repair services, provided that there was relative proximity. By adopting this model, the mussel farm would ensure its full viability apart from proposed multi-use platforms and yet would be positioned to fully leverage the opportunities they offer.

Mussel Seed Collection

Another consideration that we analysed related to mussel seed collection. FAO (2024a) has documented that obtaining a steady supply of mussel spat is the single largest challenge to mussel farming in the Netherlands. This does not represent a major challenge to this farm for several reasons. First, most mussel farming in the Netherlands is bottom culture, which does not have an inherent mussel collection process. Smart Farm (2024a), on the other hand, notes that its mussel farm can be used for seed collection purposes. Additionally, Jak et al. (2020) note how the mouths of the Rhine and Scheldt rivers (which are in the likely proximity of this farm) offer high nutrient and particle density (p.8). Finally, Buck et al. (2010) are highly positive about natural mussel seed accumulation in offshore applications (p. 266).

Technological Considerations

Regarding technological considerations needed to thrive in the offshore Dutch North Sea, it is evident that both an eider duck fence and reinforced Smart Farm equipment would be critical. Given the Bird Life International (2024) report that the eider duck is native to the Netherlands, we judged the eider duck fence to be necessary to have on hand. Regarding the harsh Dutch North Sea conditions, Smart Farm (2024c) reports that its equipment (in its conventional form) is capable of withstanding waves up to seven meters. Since the Dutch North Sea waves can be much higher than this, for the purposes of this study Smart Farm proposed to manufacture the relevant equipment with an increased degree of thickness in relevant pipe walls and ropes for an additional cost of 10 percent per unit. Further, Smart Farm (2024a) notes how their farm can be sunk to the sea bottom during storms.

We also analysed a technological advantage of the Smart Farm that supports the assumption of strong Yerseke Mussel Auction purchase prices. The Smart Farm harvesting machine operates ‘very gently’, which in turn leads to less de-clumping and fewer broken mussels (B. Aspoy, Smart Farm, email communication, December 14, 2023). This could reasonably be expected to lower labour demands experienced by mussel processing entities, in turn supporting strong mussel prices.

Farm Size Considerations

Regarding the number of mussel lines deployed, we coordinated with Smart Farm to identify the minimum number of lines necessary to yield favourable investor returns. Identifying this number was judged to be critical in view of possible concerns that might be raised by competing Dutch mussel stakeholders regarding a significantly larger farm. Further, the pioneering nature of this farm and the consequent need to employ a conservative financial approach lends additional credence to the importance of this number. It was assumed, however, that realized favourable investor returns and other favourable conditions over time could be leveraged to scale up this farm considerably, with potential cascading investor returns and other previously discussed benefits emerging accordingly.

Cost Categories

The study cost categories are a composite of those identified by Jansen et al. (2016 p. 745), Van Deurs et al. (2013), and Buck et al. (2010), and are fully enumerated in Table 1.

Some cost categories from the above three studies were not included owing to how they were specific to the respective farm model used in their respective studies. For example, since all mussels currently farmed in the Netherlands are sold at the Yerseke auction (FAO, 2024b), the land facility and mussel transportation costs included in Buck et al. (2010) were not included in our study. Lodging costs were also included after discussion with Smart Farm.

After the cost categories were identified from the above studies, we began to source the data. As part of this we elected to include inflation costs and accordingly included both cost-push and demand-pull inflation. Cost-push inflation occurs when input prices rise and consumer prices increase accordingly. It is assumed that the cost-push inflation for this project will remain at 2.5% during the first decade. On the other hand, demand-pull inflation occurs when consumer demand rises and consumer prices increase accordingly. It is assumed that the demand-pull inflation will begin at 10% and increases by 5% every third year and 1% annually thereafter.

Cost Analysis

Labor Costs

As per Statistics Netherlands (2021), the average yearly wage including bonuses for experienced workers in agriculture, forestry, and fishing (age: 50 to 54 years) is €35,810. We deferred to hiring employees who are more experienced in this sector, given the pioneering nature of this project together with the need to hire a SmartCat captain.

Overhead Costs

To calculate the hours needed to operate the boats, we used pro rata analysis. The total hours in which the boats and equipment used annually in the study by Van Deurs et al. (2013) were identified. The

Table 1. Cost Category Sources

Cost Category Name	Jansen et al. (2016)	Van Deurs et al. (2013)	Buck et al. (2010).
Smart Farm units		✓	
Eider Duck fence		✓	
Moorings		✓	✓
Navigational markings		✓	✓
Equipment transport and logistics		✓	✓
SmartCat / new vessel		✓	✓
Accessories and spare parts		✓	
Professional and consultancy fees		✓	
Lodging for Smart Farm staff			
License fees - 2 staff			✓
Contingency (extraneous) costs	✓		✓
Small boat		✓	
Labour costs	✓	✓	✓
Boat operating costs (including fuel)	✓	✓	✓
Insurance costs		✓	✓
Financing costs		✓	✓
Inflation costs (fixed costs)			
Depreciation costs	✓	✓	✓

Note: '✓' indicates that the respective cost category is mentioned in the respective source.

total for this is 2463 hours (p. 27). Then, we determined that this proposed farm requires two employees, one working .5 FTE and another .25 FTE (B. Aspoy, Smart Farm, personal email, January 18, 2021). This compares to 3.0 FTE in Van Deurs et al. (2013), where the three employees would work full time to produce a much higher yield (p. 10). After cross multiplying these values, we calculated 615 hours for operating the boats each year. From here, the operating cost per hour was calculated. Based on the findings of Van Deurs et al. (2013) we estimated that the costs of running the large and small vessels is 51 and 26 Euros per hour, respectively (p. 11). Averaging this out, the average operating cost per hour will be 38.5 Euros, which amounts to €23,677 in total boat operating costs per year.

Fixed Costs

We assumed the annual maintenance cost for the Smart Cat and other equipment at 1 percent.

Insurance Costs

As per a preliminary quote we received from Global Aquaculture Insurance Consortium (2020), an offshore mussel farm would be insured against threats such as storms and predators but not diseases throughout the policy period for a rate of between 3% and 5% (Global Aquaculture Insurance Consortium, personal email, November 16, 2020). Accordingly, we have assumed an average of a 4% annual insurance charge.

Financing Costs

As per Trading Economics (2023), the prime lending rate in the Netherlands is between 2 to 3%. We set the debt to total capitalization for this study at 40%, which is comparable to that of the aggregate mussel industry in Germany as reported by the European Commission (2019, p. 33).

Mussel Production Expectations

After communicating with Smart Farm, we projected this farm would initially produce 300 tpa in the first five years followed by a gradual increase of 100 tpa every subsequent five years for 25 years. Smart Farm (B. Aspoy, personal communication, January 18, 2021) also communicated that the pipes and nets from their mussel farm can be expected to stay intact for more than 20 years, while some of the smaller parts may need to be replaced after five to ten years. Van Deurs et al. (2013) similarly indicated that small parts (such as rope loops and navigational markings) may need to be replaced after ten years (p.19). Given that this cost is both small and difficult to predict, owing to its dependence on open North Sea conditions, we did not include it in CAPEX calculations. Given these considerations, we chose 25 years of operation as the timespan for this study.

Smart Farm (2021) projected that 25 mussel lines would each produce 12 tonnes of mussels in each farming cycle, which represents a reasonable scale that is financially viable under the model assumptions. Smart Farm also indicated that the farm could be expected to produce higher volumes of mussels over time as more mature farming practices are employed. Considered together with an increase in the number of Smart lines every five years, an increase in total mussel production to 700 tpa by the 20th year can be projected (B. Aspoy, personal communication, January 18, 2021; see 'Efficiency' in Table 2).

Financial Model

Our financial model emerged after we populated all of the assumptions, cost categories, and mussel production expectations. We estimated the intrinsic value of this farm using the discounted cash flow (DCF) valuation model. This model gives strong focus to future cash flows. We selected the DCF method over other valuation methods because it generates an intrinsic value, a growth rate, a discount rate, and detailed cash flow projections, while also facilitating understanding of growth opportunities, synergies, and competitive advantages.

We used the weighted average cost of capital (WACC) to compute the discount rate. The discount rate is the interest rate applied to future cash flows to calculate the present value of cash flows. It gives particular focus to the amount of money needed to service company debt. The WACC is the average cost of financing the debt and equity of a company and is weighted according to the situation of the company analysed. WACC is calculated as follows:

$$WACC = (E/V \times Re) + ((D/V \times Rd) \times (1 - T)).$$

Where *E* is the market value of equity, *V* is the total market value of equity and debt, *D* is the market. The Capital Asset Pricing Model (CAPM) was used to calculate the project cost of equity of 9.71%. This generated a WACC / discount rate of 6.73% which was subsequently used to calculate the value of this farm. The derivation of the WACC value is elucidated further in Table 2 below.

Results

This study advocates for an offshore mussel farm in the Dutch North Sea with an initial production capacity of 300 tpa to be scaled to 700 tpa in 25 years, based on more mature farming practices (see 'Efficiency' in Table 3) and additional Smart Farm units (B. Aspoy, personal communication, January 18, 2021). The aggregate anticipated production is seen in Table 3. The anticipated selling price of mussels is seen in Table 4 and was projected based on the selling price of mussels at the Yerseke Mussel Auction.

Capital Expenditure

A detailed breakdown of the capital expenditure to generate 300 tonnes annually is summarized in Table 5.

Operational Expenditure

The operating costs for one kilogram of mussels are summarized in Table 6. As seen above this farm would achieve a favourable margin of € 0.9247 (72.5%) based on sales price (€ 1.2757) and operating costs (€ 0.351). A discussion of Operational Expenditure and other costs is displayed in Table 7.

Annual Profits

Financial Projection

A summary of the projected financial results is presented in Table 7. This study projects a positive NPV

Table 2. Weighted Average Cost of Capital (WACC)

Capital Structure	
Debt to Total Capitalization	40.00%
Equity to Total Capitalization	60.00%
Debt / Equity	**66.67%**
Cost of Equity	
Risk Free Rate	1.63%
Equity Risk Premium	6.01%
Levered Beta	1.34
Cost of Equity	**9.71%**
Cost of Debt	
Cost of Debt	3.00%
Tax Rate	25.0%
After Tax Cost of Debt	**2.25%**
WACC	**6.73%**

Table 3. Aggregate Production

	Project Year	Number of Mussel Lines	Production (kg) per Mussel Line	Efficiency (kg)	Net (kg)
Total net production volume (kg)	Inception	25	12,000	0	300,000
	5	32	12,000	16,000	400,000
	10	40	12,000	20,000	500,000
	15	48	12,000	24,000	600,000
	20	56	12,000	28,000	700,000

Table 4. Yerseke Mussel Auction Rates

Season	Average purchasing price
2015/2016	104.67
2016/2017	83.3
2017/2018	108.84
2018/2019	109.3
2019/2020	127.57

Table 5. Total Capital Costs

Summary of Capital Expenses	Amount in Euros
Offshore Smart Farm Units*	288,750
Eider Duck Fence	40,000
Moorings	198,000
Navigational Markings	20,800
Transport and logistics	6,961
SmartCat	1,000,000
Accessories and Spare Parts	35,000
Small boat	20,000
Professional and consultancy fees (Smart Farm) 5 days x Euro 600	3,000
Lodging for Smart Farm staff during installation	2,135
License fees - 2 staff	228
Contingency (5%)	80,476
Total capital costs	**1,695,350**

Table 6. Operating Costs

Summary of Operating Costs for One Kilogram of Mussels	(Based on 300 tpa) Amounts in Euros
Labour costs (Euro 35,810 per year)	0.119
Overhead costs – Boats (/kg) 615 Hrs. x Euro 38.5=Euro 23,677.5	0.079
Fixed costs (/kg)-Maintenance cost of boats and equipment=1,020,000	0.034
Insurance costs (/kg) 300,000 kgs x1.2757=382,710 @ 4%	0.051
Financing costs (/kg) Euro ((1,695,350 x 40%)*3%)/300,000 kg	0.068
Total costs sold	**€ 0.35**

of € 3,479,178 utilizing a 6.73% discount rate. The NPV, calculated as the difference between the present value of discounted cash inflows and outflows over a 25-year period, is a metric that depicts the total value of an investment. The NPV was calculated using the following formula:

$$NPV = \sum_{t = 0}^n \frac{C_t}{(1 + r)^t} - C_0$$

In this formula, C_t = net cash flow at time (t); r = discount rate; n = number of periods; C_0 = initial investment. Since the NPV is positive, the project is financially viable. Since this is a time bound project, a terminal value was not used in the valuation process. The expected IRR for this project is 19.78%, which indicates a favourable return. The IRR is a metric used to assess the profitability of a project and is the annualized rate of return that makes the NPV of all cash flows equal to zero. A project is accepted only if its IRR projects returns higher than the cost of capital.

Given the assumed mussel selling price of € 1.5181, the payback period for this project can be expected to be 7.44 years. The most significant financial sensitivity of this project is the selling price of mussels at the Yerseke Mussel Auction. Given this, we analysed the following scenarios. If the mussel price decreased by 8.7% to € 1.3905 per kg, the payback period would be 8.22 years. This would also translate to a resultant 18.79% IRR and a € 3,284,816 NPV. If the mussel selling price increased by 8.84%, the IRR, NPV, and payback period would become 19.99%, € 3,652,447, and 8.33 years respectively. Since the results of this sensitivity analysis are similar to those found by the primary analysis, the results remain robust.

As part of the sensitivity analysis, the breakeven price and the breakeven outlet were calculated using the discount rate of 6.73%. The breakeven price is the price at which the NPV equals zero and was calculated to be 0.122 or 12.23%. The breakeven output is the value of the mussels sold at which the NPV equals zero and was calculated to be € 2,487,579.58.

Discussion

This study projects strong returns for a proposed Smart Farm that uses reinforced equipment on the open

Dutch North Sea. The meaningful success of Offshore Shellfish notwithsanding, the extraordinarily harsh North Sea conditions continue to render this project to have an experimental element. As such, investors may find a pilot study comparable to Project Edulis helpful to further justify the technical viability of this farm. As part of this the SmartCat could be leased to commercial fishing companies during hours it is not in use. While analysing profit opportunities from leasing the SmartCat is outside the scope of this study, this could offset the costs of the SmartCat significantly.

A second limitation has to do with additional profit opportunities that mussel seed collection could provide for this farm, an analysis of which is outside the scope of this study. Jak et al. (2020) reported an estimate that up to 25% of the mussel seed requirements of Dutch aquaculture could come from offshore collection (p.7). Their proposed mussel farm was projected to return €4.4 million from mussel seed sales (p.19).

A third limitation of this study relates to the time period that offshore permits would be in effect. The Ministry of Agriculture, Nature, and Food Quality in the

Table 7. Annual Profits

Year	**1**	**2**	**3**	**4**	**5**
Inflation (Cost)		2.50%	2.50%	2.50%	2.50%
Inflation (Price)		10%	15%	16%	17%
Revenue and Cost	*Unit*	*Unit*	*Unit*	*Unit*	*Unit*
Total net production volume (kg)	300,000	300,000	300,000	300,000	300,000
Expected price (Euro/Kg)	1.2757	1.4033	1.4671	1.4798	1.4926
Revenue (Euro)	382,710	420,981	440,117	443,944	447,771
Operation cost (Euro)	105,343	107,977	110,676	113,443	116,279
Yearly Fixed cost	45,856	47,002	48,177	49,382	50,616
Variable cost	59,488	60,975	62,499	64,062	65,663
Depreciation at 10% (1,20,000*10%)	40,800	40,800	40,800	40,800	40,800
Total Cost (Euro)	146,143	148,777	151,476	154,243	157,079
EBIT	236,567	272,204	288,640	289,700	290,691
Taxes	59,142	68,051	72,160	72,425	72,673
Net Profit	177,425	204,153	216,480	217,275	218,019
Tax Shield	15,285	15,413	15,543	15,676	15,813
Cash Flow	233,510	260,366	272,823	273,752	274,632

Year	**6**	**7**	**8**	**9**	**10**
Inflation (Cost)	2.50%	2.50%	2.50%	2.50%	3.00%
Inflation (Price)	18%	19%	20%	21%	22%
Revenue and Cost	*Unit*	*Unit*	*Unit*	*Unit*	*Unit*
Total net production volume (kg)	400,000	400,000	400,000	400,000	400,000
Expected price (Euro/Kg)	1.5053	1.5181	1.5308	1.5436	1.556
Revenue (Euro)	602,130	607,233	612,336	617,439	622,542
Operation cost (Euro)	119,186	122,166	125,220	128,351	132,201
Yearly Fixed cost	51,882	53,179	54,508	55,871	57,547
Variable cost	67,305	68,987	70,712	72,480	74,654
Depreciation at 10% (1,20,000*10%)	40,800	40,800	40,800	40,800	40,800
Total Cost (Euro)	159,986	162,966	166,020	169,151	173,001
EBIT	442,144	444,267	446,316	448,288	449,540
Taxes	110,536	111,067	111,579	112,072	112,385
Net Profit	331,608	333,200	334,737	336,216	337,155
Tax Shield	15,954	16,098	16,245	16,396	16,582
Cash Flow	388,362	390,098	391,782	393,412	394,537

Year	**11**	**12**	**13**	**14**	**15**
Inflation (Cost)	3.00%	3.00%	3.00%	3.00%	3.00%
Inflation (Price)	23%	24%	25%	26%	27%
Revenue and Cost	*Unit*	*Unit*	*Unit*	*Unit*	*Unit*
Total net production volume (kg)	500,000	500,000	500,000	500,000	500,000
Expected price (Euro/Kg)	1.569	1.582	1.595	1.607	1.62
Revenue (Euro)	784,556	790,934	797,313	803,691	810,070
Operation cost (Euro)	136,167	140,252	144,460	148,794	153,257
Yearly Fixed cost	59,273	61,052	62,883	64,770	66,713
Variable cost	76,894	79,201	81,577	84,024	86,545
Depreciation at 10% (1,20,000*10%)	40,800	40,800	40,800	40,800	40,800
Total Cost (Euro)	176,967	181,052	185,260	189,594	194,057
EBIT	607,588	609,882	612,053	614,097	616,012
Taxes	151,897	152,470	153,013	153,524	154,003
Net Profit	455,691	457,411	459,040	460,573	462,009
Tax Shield	16,773	16,971	17,174	17,383	17,598
Cash Flow	513,265	515,182	517,013	518,756	520,408

Table 7. Annual Profits (continued)

Year	16	17	18	19	20
Inflation (Cost)	3.00%	3.00%	3.50%	3.50%	3.50%
Inflation (Price)	28%	29%	30%	31%	32%
Revenue and Cost	*Unit*	*Unit*	*Unit*	*Unit*	*Unit*
Total net production volume (kg)	600,000	600,000	600,000	600,000	600,000
Expected price (Euro/Kg)	1.632896	1.646	1.658	1.671	1.684
Revenue (Euro)	979,738	987,392	995,046	1,002,700	1,010,354
Operation cost (Euro)	157,855	162,591	168,281	174,171	180,267
Yearly Fixed cost	68,714	70,776	73,253	75,817	78,470
Variable cost	89,141	91,815	95,029	98,355	101,797
Depreciation at 10% (1,20,000*10%)	40,800	40,800	40,800	40,800	40,800
Total Cost (Euro)	198,655	203,391	209,081	214,971	221,067
EBIT	781,083	784,001	785,965	787,729	789,287
Taxes	195,271	196,000	196,491	196,932	197,322
Net Profit	585,812	588,001	589,473	590,797	591,965
Tax Shield	17,820	18,049	18,324	18,608	18,902
Cash Flow	644,432	646,850	648,597	650,205	651,668
Year	**21**	**22**	**23**	**24**	**25**
Inflation (Cost)	3.50%	3.50%	3.50%	3.50%	3.50%
Inflation (Price)	33%	34%	35%	36%	37%
Revenue and Cost	*Unit*	*Unit*	*Unit*	*Unit*	*Unit*
Total net production volume (kg)	700,000	700,000	700,000	700,000	700,000
Expected price (Euro/Kg)	1.696681	1.709	1.722	1.735	1.748
Revenue (Euro)	1,187,677	1,196,607	1,205,537	1,214,466	1,223,396
Operation cost (Euro)	186,577	193,107	199,865	206,861	214,101
Yearly Fixed cost	81,217	84,059	87,001	90,046	93,198
Variable cost	105,360	109,048	112,864	116,815	120,903
Depreciation at 10% (1,20,000*10%)	40,800	40,800	40,800	40,800	40,800
Total Cost (Euro)	227,377	233,907	240,665	247,661	254,901
EBIT	960,300	962,700	964,871	966,806	968,495
Taxes	240,075	240,675	241,218	241,701	242,124
Net Profit	720,225	722,025	723,653	725,104	726,372
Tax Shield	19,207	19,522	19,849	20,186	20,536
Cash Flow	780,232	782,347	784,302	786,090	787,707

Netherlands (2021) directly informed us that the project which received temporary offshore mussel licenses in 2011 (Jansen et al., 2016, p.747) did not proceed because the three-year duration permitted was not considered sufficient for investing purposes (A. Kouwenhoven, personal email, April 13, 2021). This limitation underscores that a permanent fixed location cannot be guaranteed for our proposed farm and also highlights the need to be able to relocate the farm. This is technically feasible with a tugboat at an extraordinarily slow speed, as per the manufacturer (B. Aspoy, Smart Farm, Microsoft Teams communication, July 2, 2020).

A fourth limitation is the sensitivity that a high volume mussel farm could represent to existing Dutch mussel farmers. FAO (2024a) reports that the number of mussels harvested in the Netherlands annually is 50,000 to 60,000 tpa. While the projected 600 tpa from this project does not represent an extraordinary increase, a fully scaled farm comparable to that depicted by Van Deurs et al. (2013) could result in controversy. Accordingly, the initially small size of this operation is considered justified. In a fully scaled operation, however, existing stakeholder concerns could be allayed by pivoting in part to a mussel seed collection operation, in turn serving a critical purpose for competitors. Further, a fully scaled operation could pivot in significant part to an export-based model. This will be discussed more below.

As we noted in the study methodology section, the study objectives are to assess the following: The relevant conditions necessary to realize this proposed farm, the financial feasibility of this farm, and the contribution of this farm to global food security. The literature review established that there is meaningful European and global mussel demand, that offshore mussel farming can be profitable, that the Smart Farm represents a mature and productive technology in harsh natural conditions, and that mussel farms can be symbiotic with multi-use offshore platforms. It further established that offshore mussels offer lower environmental impact challenges and more optimal health benefits than their nearshore counterparts. It also identified that the Dutch regulatory environment for offshore mussel farming is conducive and clear. Finally, it established that high volume mussel aquaculture could help advance global aquaculture, provided that mussel production and retail costs are reduced. Accordingly, the first objective has been met.

The second objective of this study (to assess the financial feasibility of this proposed farm) was also met. This study found an IRR of 19.87% and and an NPV of

€3.5 million. The WACC (6.73%) and EBIT are also favourable and supportive of the study IRR and NPV. The IRR of our study is preferable when compared to European mussel farms in general. Avdelis et al. (2021) compared the profitability of European mussel farms that employ raft, longline, bouchot, and bottom culture methodologies. They found production costs per kilogram to farmgate price per kilogram ratios of € .31: € .37, € .62: € .66, € 1.65: € 2.04, and € 0.90: € 1.25, respectively (p.96). They also noted that labour is a 'main cost component' for each methodology (p.95). The production costs per kilogram to farmgate price per kilogram ratio in our study (€ 0.351: € 1.27) stands at significant variance to these farms and adds credence to the fully mechanized and offshore properties of this farm.

The third objective of this study (to assess the contribution of this farm to global food security in view of the technological maturity, mobility, scalability, high mechanization and high production of the Smart Farm) was also met. The production cost of one kilogram of mussels from our proposed farm (€ 0.351) and their farmgate cost per kilogram sold at the Yerseke Mussel Auction (€ 1.27) is significantly lower than the retail price of blue mussels sold in large mussel markets around the world. OEC (2024) notes that the top importers of mussels are Belgium ($95.3 million), France ($47.9 million), the Netherlands ($45.7 million), Italy ($40.2 million), and the United States ($38.4 million). As of January 27, 2024, the kg retail price of blue mussels in each country is between € 6.82 and € 10.46, € 7.22 and € 9.51, € 6.23 and € 22.39, € 5.37 and € 10.47, and € 6.35 and € 10.89, respectively (Selina Wamucci, 2024). The highly competitive price of the mussels produced using this farm could reasonably be expected to continue in an export-focused scenario involving a plurality of fully scaled Smart farms. Greater degrees of mechanization and production could also lower production costs further, in turn passing on meaningful savings to customers globally. This scenario also appreciates the finding of Azra et al. (2021) that a critical issue to realizing global shellfish potential is reducing production costs. In leveraging this the Netherlands and the world itself could transition from relatively primitive forms of mussel farming to a more evidence-based, mechanized, and high production future. The services of the Yerseke Mussel Auction and its mussel wholesalers could also be more fully leveraged, in turn bringing expansion to the Dutch mussel industry. An export driven model is also regulatorily consistent with European export law. The Official Journal of the European Union (2015) documents that the export of products (inclusive of blue mussels) from EU is not under quantitative restrictions (p.34). Further, no VAT would be applied in this scenario, as the Netherlands Chamber of Commerce (2024) indicates that exports from EU to non-EU countries are VAT taxed at 0%.

Conclusion

Kravec (2019) quotes Costello as saying "The ocean has great, untapped potential to help feed the world in the coming decades, and this resource can be realized with a lower environmental footprint than many other food sources. Yet ocean health and ocean wealth go hand-in-hand. If we make rapid and far-reaching changes in the way we manage ocean-based industries while nurturing the health of its ecosystems, we can bolster our long-term food security and the livelihoods of millions of people." This study lends significant credence to this statement. Given the finding of Gentry et al. (2017) that 1,500,000 kilometers^2 of offshore ocean space could be mussel farmed globally together with pressing global demands for affordable protein, this study serves an important pioneering purpose. The sustainable implementation of this farm in one of the most volatile seas together with successful financial outcomes could pave the way for a plurality of fully scaled Smart farms in many locations globally.

Further, the financial outcomes projected in this study are significantly more favourable than those expected with less advanced technology applications. Given the heavy mechanization of other types of agriculture and aquaculture, this conclusion is unsurprising and yet needs to be underscored. Smart Farm (2023) notes that traditional mussel farms require the farmer to mount and remount each collector mussel line in a labour-intensive manner each time that they harvest or thin said line. By contrast, every aspect of mussel husbandry, thinning, and harvesting completed with Smart Farm technology is completed by machine, to the point that the hands of the farm workers never come into contact with the mussels or mussel lines in the normal course of events. Simply stated, the machines do all the work, and the farm workers operate said machines (B. Aspoy, email communication, December 14, 2023). This is consistent with FAO (2024), who found that critically adding economic value to the mussel industry may be through producing mussels of superior quality from a unique origin using a particular production methodology, particularly considering rising production costs.

The findings of this study also speak to an earlier statement by Holmyard cited by FAO (2014) that offshore mussel farming profitability is unproven, suggesting that with the right technology Europe is moving beyond this, and given the right conditions is poised to leverage its vast ocean spaces for high volume offshore mussel production. Given the need for the Dutch mussel industry to develop farms offshore, given the favourable investor returns offered by the Smart Farm compared to other technologies, and given the inherent qualities of technological maturity, mobility, scalability, high mechanization and high production offered by Smart Farm, strong support is lent to the conclusion that an offshore Smart Farm is among the most viable strategies for the Dutch mussel industry to move forward.

By developing this farm, the conditions could be set for the Netherlands to increasingly leverage and develop its offshore ocean economy, in a way that is sustainable and even restorative of the Dutch North Sea. With a stellar ocean engineering record that is unparalleled by any other country, the Netherlands stands to continue to lead the world in developing sea-based economic opportunities in a measured, tempered, and evidence-based manner. Future research should focus on coordinating with Dutch regulators to give greater offshore mussel farm location predictability to investors, in turn, increasing investor confidence. It would be ideal for offshore mussel farmers to be able to depend on designated areas of the Dutch North Sea as wind farming companies do. Future research should also focus on assessing the economic viability of other aspiring or actualizing offshore ocean businesses to strengthen the business case for the forward-thinking multi-use platforms that are being planned in the Dutch North Sea. In turn, these platforms can be expected to increase the prospects of the ocean economy taking on a momentum all its own, with a plethora of be nefits across a multitude of domains.

This study helps to establish that the investment opportunities of advanced technology offshore mussel farming are not to be ignored. By strategically leveraging the opportunities found in farming this distinctive organism in this manner, investors stand to add value to humanity in a variety of ways across the domains of employment, sustainability, ocean remediation, nutrition science, maritime engineering, aquaculture, the ocean economy, world food supply, and upward economic mobility on which future generations can build.

Ethical Statement

Not applicable.

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Author Contribution

Conceptualization: HH & JVD, Data Curation: HH & JVD, Formal Analysis: HH, Investigation: HH & JVD, Methodology: HH, Project Administration: JVD, Supervision: HH, Visualization: HH & JVD, Writing - original draft: JVD, Writing -review and editing: HH & JVD.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper. The authors alone are responsible for the content and writing of this paper.

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