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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, previous financial feasibility studies, 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.

Keywords: Offshore mussels, offshore aquaculture, offshore mariculture, offshore shellfish, offshore bivalves

Main text below:

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 open North Sea represent one of many unlimited opportunities for aquaculture scalability and the benefits thereof. While horizon-spanning offshore European aquaculture operations are not in the foreseeable future, investors would be remiss to ignore the benefits that can attend smaller offshore mussel farms that could potentially serve as precursors of said operations. Van der Schatte et al. (2018) 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 $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). Other scholars have similarly highlighted the advantages of mussels. Zoologist David Willer is quoted by Lovell (2023) as saying that bivalve aquaculture has a lower environmental footprint than many crops in terms of land, freshwater use, and greenhouse gas emissions. Shumway (2011) noted that the environmental impact of shellfish culture is usually beneficial, and that shellfish culture provides a multitude of additional environmental services (p. xv). Concerns related to mussel farming's environmental impact are often associated with factors such as limited water circulation and oxygenation (European Commission, 2023) and mussel dredging practices (National Oceanic and Atmospheric Administration [NOAA], 2011).

Mussel farming also significantly contributes to global food security. Azra et al. (2021) conducted an assessment on shellfish as a contributor 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 (2023), 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 (2023) 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, reinforcing these nutritional advantages.

The intersection between the above documented benefits of mussels and the 17 sustainable development goals of the United Nations (2022) 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 both in the North Sea and worldwide.

In addition to these benefits, investors should consider other 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 (2023a) 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 (2023b) further explains 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 heavily underscores the significantly lower labour inputs and higher mussel production offered by the Smart Farm. National Oceanic and Atmospheric Association (NOAA, 2023) documents that bottom and raft culture mussel farming is “hard work, muddy, and messy.” The Mussel Industry Council of Prince Edward Island (2023) notes how the longline system used by PEI 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, 2023a) 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 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.

Our study found an IRR of 19.78% and an NPV of €3,479,178 for this proposed farm. By exploring beyond the current academic literature and the existing mussel operations in the Netherlands, while considering the advantages provided by the Smart Farm, our study endeavours to aid the academic field, the Netherlands, and the world to transition from less sophisticated forms of mussel farming toward a more evidence-based and academically rigorous future.

Literature Review

The academic literature provides important information that can help inform and facilitate our proposed farm. Regarding the mussel market in Europe, FAO (2023b) notes that for some time Europe has had a high value market. Between 1985 and 2000, international mussel trade as a percentage of domestic supply increased from 14% to 35%, with France importing half of its mussels. The market has also risen consistently in terms of volume in the last twenty years. The academic literature also indicates a scarcity of high-performing offshore mussel farms in Europe at present. FAO (2014) quotes Holmyard to indicate that profitability using an offshore approach has not been proven (p. 45). Holmyard himself, however, is presently developing Offshore Shellfish (2023), a shellfish farm that is expected to produce 10,000 tonnes of mussels per year in Lyme Bay, England. In a more recent study, Buck et al. (2017) highlighted that well-established offshore mussel farms are only found in France and Italy (p. 46, 47).

Buck et al. (2010) completed a study of the logistic and economic feasibility of integrating long line mussel culture into German offshore wind farms and found that it could yield an IRR of 14.73% or 28.11% depending on whether it used a new or used boat, and whether existing capacities of other mussel farmers were used. They also found that two other scenarios involving labour-intensive methods to obtain mussel seed were not profitable (p. 272). Van Den Berg et al. (2017) found that a semi-submerged longline system integrated into Dutch wind farms could yield a positive IRR and NPV. Bartelings et al. (2014) found that the same kind of mussel farm could yield an expected return on investment of between 4.9% and 9.6%, depending on economic conditions and the degree of synergy between the wind and mussel operations (p. 9).

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 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).

An academic examination of the environmental impact challenges faced by nearshore mussel operations underscores the value of an offshore approach. Several studies have documented specific environmental impact concerns from mussel operations in inshore environments where low water circulation is present (Kaspar et al. 1985; Stenton-Dozey et al. 1999; Chamberlain et al. 2001; Nizzoli et al. 2005; Hargrave et al. 2008). FAO (2023a) also notes that the mussel farming sector of the Netherlands currently depends heavily on dredging to generate mussel seed. 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 provides additional support for offshore operations. Pavon et al. (2022) found that 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. Baralla 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. Airas (2003) analysed mussels in the Byfjorden and Bergin areas in Western Norway and found that samples from the Bergin area had 'elevated' levels of copper, zinc, and lead. Cadmium and lead concentrations were also found to be significantly higher in subtidal mussels than those from environments with higher fluctuations. 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.

Regarding the Dutch regulatory environment, it is evident that the Government of the Netherlands has been directly encouraging 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 (2023b) 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).

The academic literature on the contribution of mussels to global food security offers promising possibilities. Costello et al. (2020) specifically notes that bivalve mariculture currently accounts for 5% of global seafood. By 2050 it is projected under current conditions to grow to 6%. In a scenario where demand might become extreme, it is projected to grow to 27% of global seafood production, 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. Given the potential mussels offer to global food security, given that European offshore mussel farming has been demonstrated to be profitable, 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

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 proposed farm there are several guiding factors that we considered. FAO (2023a) notes that presently all mussels farmed in the Netherlands are sold at the Yerseke auction. Given this, proximity to Yerseke for mussel sales 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. The FAO (2023a) 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 (2023a), 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 (2021) report that the eider duck is native to the Netherlands, together with the report of the European Commission (2008) that the neighbouring Baltic and Wadden Sea have a combined population of 760,000 common eider ducks (p.136), we judged the eider duck fence to be necessary to have on hand. Regarding the harsh Dutch North Sea conditions, Smart Farm (2023c) 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 (2023a) 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.

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		✓	□
Labor 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.

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, 2023a), 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 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) and is consistent with Engle and Stone (1997), who found that lenders prefer that owners possess a 60% equity (p.3).

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.

Table 2

Weighted Average Cost of Capital (WACC)

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%**

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 can be found in Table 3.

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

The anticipated selling price of mussels can be found in Table 4 and was projected based on the recent selling price of mussels at the Yerseke Mussel Auction.

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

Note: Data is from A. Risseux, Yerseke Mussel Auction, personal email, August 24, 2020

Average purchasing price is per 100 KG in Euros

Capital Expenditure

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

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	1,695,350

** includes 10% added to the price to reinforce for offshore operations*

Note: Data is from Smart Farm, personal email, November 17, 2020

Operational Expenditure

The operating costs for one kilogram of mussels are summarized in Table 6.

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 operating costs	**€ 0.35**

As indicated above this farm would achieve a favourable margin of € 0.9247 (72.5%) based on sales price (€ 1.2757) and operating costs (€ 0.351). The major Operational Expenditure (OPEX) categories for this model are as follows: labour costs, overhead costs, fixed costs, insurance costs, and financing costs. A detailed discussion of Operational Expenditure and other costs is displayed further in Table 7.

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

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

Financial Projection

A summary of the projected financial results is presented in Table 7. This study projects a positive NPV 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. The average annual increase in selling price per 100 kg of mussels was 6.82% for the five year period assessed, and represents significant fluctuations over time. Given this consideration, we analysed the following scenarios. If the mussel price decreased by 8.7% to € 1.3905 per kg, the payback period for this project 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 positive considerations of this reinforced farm already documented above notwithstanding together with the success of comparable operations of Offshore Shellfish, it is important to acknowledge that the extraordinarily harsh North Sea conditions continue to render this project to have an experimental element. As such, investors may find an extra pilot study (using an even smaller number of reinforced Smart units) helpful to further justify the technical viability of this farm. As part of this the SmartCat, the largest expense associated with this farm, can be leased to commercial fishing companies for their purposes particularly since it would only be used part-time by this farm. While analysing profit opportunities from leasing the SmartCat is outside the scope of this study, it should be noted that 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 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. Simultaneously, it underscores the importance of being able to transport it to a new location. 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). While having to relocate for new permitting purposes would be far from ideal, it would also be far from insurmountable.

A fourth limitation is the sensitivity that a high volume mussel farm could represent to existing Dutch mussel farmers. FAO (2023a) 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 commercially viable but critical purpose for other mussel farmers in the Netherlands. Further, a fully scaled operation could pivot in significant or complete part to an export-based model. This will be discussed more below.

As we noted in the introduction, 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 play a strong role in 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 an NPV of €3.5 million. This is particularly favourable when compared to the offshore mussel financial feasibility studies analysed in the literature review. The WACC (6.73%) and EBIT are also favourable and supportive of the study IRR and NPV. Given that our proposed farm would employ a new boat, it is evident that the IRR generated by this farm would be preferable to the farm depicted by Buck et al. (2010) that found an IRR of 14.73% in the scenario where a new boat would be employed (p.272). The IRR of this study is also preferable to the 4.9% and 9.6% return on investment found by Bartelings et al. (2014). The IRR of our study is also preferable when compared to European mussel farms in general, including those that are nearshore. Avdelas 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 deriving from fully leveraged scalability in this scenario could also lower the production cost of mussels produced 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. The services of the Yerseke Mussel Auction and its mussel wholesalers could also be more fully leveraged in this scenario, given the low farmgate cost per kilogram sold there, in turn bringing expansion to the auction and 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 Holmyard's earlier statement 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 benefits 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.

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Tables

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.

Table 2

Weighted Average Cost of Capital (WACC)

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

Note: Data is from Yerseke Mussel Auction, personal communication, August 24, 2020

Average purchasing price is per 100 KG in Euros

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**

** includes 10% added to the price to reinforce for offshore operations*

Note: Data is from Smart Farm, Personal Communication, November 17, 2020

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**

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

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

Highlights

• Offshore mussel farming in the Dutch North Sea can be profitable.

• An offshore SMART Farm can generate an IRR of 19.78% and an NPV of €3,479,178.

• The most viable strategy for mussel industry development in the Netherlands is offshore.

• SMART Farm technology is mature and offers meaningful scalability.

• Proliferation of offshore mussel farms can help meet many of the United Nations SDGs.