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Abstract:

This paper analyzes the financial feasibility of a mussel farm that employs the SMART Farm approach with reinforced equipment in the offshore Dutch North Sea. An IRR of 19.78% and an NPV of €3,479,178 was found for this 25 year project. While this farm could exist fully independent of any future multi-use platforms on the offshore Dutch North Sea, it could potentially have a symbiotic relationship with said platforms. An analysis of the Dutch regulatory landscape suggests that this farm could reasonably be expected to proceed, although its physical location may need to shift at least once in its lifetime. Through pursuing this farm and similar mussel farming projects, investors can help advance humanity across a variety of domains including employment, sustainability, ocean decarbonization, the ocean economy, nutrition science, maritime engineering, aquaculture, world food supply, and upward economic mobility. These domains intersect directly with Sustainable Development Goals 1 (No Poverty), 2 (Zero Hunger), 3 (Good Health and Well-Being), 8 (Decent Work and Economic Growth), 12 (Responsible Consumption and Production), and 14 (Life Below Water) of the United Nations.

Keywords: SPACE@SEA, 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 the many largely 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 similar operations of smaller scale. In particular, they would be remiss to overlook offshore mussel farms. Van der Schatte et al. (2018) have documented the far-reaching ecological benefits of bivalves. These include that farmed bivalves remove 6000 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 habitat for other marine life through their sediment (p. 6). Bivalve shells also can provide materials for poultry grit, fertiliser and lime, and construction materials (p. 8). Bivalves also increase seabed roughness (p. 5) and potentially play a role in carbon sequestration (p. 12). Other academics have also been positive about the benefits of mussels. Zoologist David Willer is quoted by Lovell (2023) as saying that bivalve aquaculture has a lower environmental footprint than many crops in regards to land, freshwater use, and greenhouse gas emissions. In addition to documenting many of the aforementioned benefits, Shumway (2011) noted that environmental impact of shellfish culture is typically beneficial and that shellfish culture provides a multitude of additional environmental services (p. xv).

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) notes also 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).

The intersection between the above documented benefits of mussels and the seventeen sustainable development goals of the United Nations (2022) is also highly noteworthy. Sustainable Development Goals 1,2,3,8,12, and in particular 14 which are respectively No Poverty, Zero Hunger, Good Health and Well-Being, Decent Work and

Economic Growth, Responsible Consumption and Production, and Life Below Water can reasonably be expected to be meaningfully advanced through a proliferation of offshore mussel farms on the North Sea and globally.

Together with these benefits, investors need to consider other emerging developments on the North Sea. The recently completed SPACE@SEA project successfully developed a technologically and financially feasible design concept for multi-use platforms in the Mediterranean and Dutch North Sea. The success of this project underscores the possibilities that are emerging for future sustainable ocean development, including those that can be realized through mussel farming. In view of these developments, this study analyzes the financial feasibility of an offshore mussel farm in the Dutch North Sea.

The approach to mussel farming applied in this study is the Smart Farm approach. Smart Farm (2023a) notes that the Smart system has a highly mechanized process that eliminates the safety concerns and extensive manual labor 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 each hour. The system is resilient in that it can be installed and remain in place for 25 years. Further, the system has inherent mussel seed collection qualities that saves additional labor. Smart Farm (2023b) notes that the husbandry and harvesting machine on the SmartCat employs brushes which can be adjusted in their proximity to the mussels to allow for both mechanized cleaning and harvesting, in turn augmenting the mechanized aspects of this farm.

In the second section of this article, the authors discuss the literature on offshore shellfish aquaculture profitability, the SMART Farm approach, the SPACE@SEA project, and the Dutch regulatory environment. In the third section, the authors articulate and defend the proposed model of the mussel farm for this study. As part of this, how the proposed mussel farm can develop a symbiotic relationship with operations on future offshore platforms, together with location, technical, and study methodology considerations are discussed. In the fourth section, the results of this study are discussed. Finally, the authors identify the findings of the study and future research recommendations.

Regarding the mussel market in Europe, FAO (2023a) notes that for some time Europe has had a high value market. International mussel trade as a percentage of domestic supply rose from 14 to 35 percent between 1985 and 2000, with France importing half of its mussels. The market has also risen consistently in terms of volume in the last twenty years. There is not an abundance of high performing offshore mussel farms in Europe today. FAO (2014) quoted 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. More recently, Buck et al. (2017) noted that only France and Italy have well-established offshore mussel farms (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 labor-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 the degree of synergy between the wind and mussel operations and economic conditions (p. 9).

Regarding the academic literature on SMART Farm, the literature suggests that the SMART Farm is a mature, high yield, and high 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 one application of the Smart Farm 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 the sometimes paramount importance of utilizing an eider duck fence in order to avoid mussel 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% Internal Rate of Return (IRR) and a Net Present Value (NPV) of 19.8 million Euros (p. 11). They also noted this farm could produce 20,000 tons of mussels each year, and included an eider duck fence in the costs of the study in order to ensure no duck predation would occur (p. 10, 23). Van Deurs (2013) elsewhere noted 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 productive capabilities of Smart Farm operations, Smart Farm connected the authors to one of their customers. This customer confirmed that they use the Smart Farm to generate between 10 to 15 tons per unit of 100 meters each harvest cycle (Smart Farm customer, personal email, February 4, 2021).

The academic literature on multi-use platforms in the Dutch North Sea offers promising possibilities that relate to offshore mussel farming. After comprehensively analyzing the profitability of having a living space, an energy hub, a transport and logistics hub, and aquaculture on offshore platforms, Ahrouch and Breuls (2020) writing for Space@Sea concluded that the creation of modular islands on both the North and Mediterranean Seas could be ‘a costly, yet beneficial solution’, with the latter sea being more economically feasible than the former (p. 6). Writing on behalf of the same project, Jak et al. (2020) noted that a mussel farm using four floating modules for the purposes of maintenance, operation, and mussel processing could yield an IRR of 7.4% and would yield 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) completed an extensive analysis of the aquaculture opportunities that would be afforded on the Dutch North Sea on offshore multi-use platforms. They analyzed how seaweed, mussels, and finfish would perform, and concluded that mussel farming offers the most biological, technical, and commercial potential (p. 740). The authors further noted a scarcity of economic feasibility studies for offshore mussel farming on single use and multi-use platforms (p. 744), but completed a brief feasibility study that demonstrated that mussel farms integrated into offshore wind farm can be profitable (p. 745).

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), it was suggested that the designed 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). Bartelings et al. (2014) noted that 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 (p. 13).

An offshore mussel farm also appears to be a wise option from the vantage point of the aggregate mussel industry in the Netherlands. The Food and Agriculture Organization of the United Nations (2023b) has noted that since 1987 there have been no new licenses granted in Holland for farming mussels. This appears to be highly attributable to limited nearshore space; Jansen et al. (2016) indicate that this nearshore 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 put to use (p. 747). Given all of the considerations documented in this literature review, it appears that the present is an opportune time for offshore mussel farming in the Dutch North Sea, both in terms of regulatory compliance and profitability.

Materials and Methods

The authors began this study by approaching Smart Farm and requesting to complete a study with them. After receiving their agreement, the cost categories were identified. The 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). Jansen et al.’s study (2016) highlights the importance of the cost categories of fixed costs, repair costs, labor costs, extraneous costs, and price elasticity, all of which were accounted for. While this study also highlights the importance of transport costs (p. 745), the authors elected not to include these, as FAO (2023c) notes that presently all mussels farmed in the Netherlands are sold at the Yerseke auction. Accordingly, the transportation costs are assumed by other parties. Buck et al. (2010) identify many farm infrastructure costs in the capital costs of their farm. With that said, all of these are specific to the technology employed by their farm (p. 269-270), and as such are not relevant to the proposed farm in this study. That said, costs associated with a new vessel, licenses, fuel, wages, repair and maintenance, interest on capital, depreciation, and extraneous costs are all noted in their study (pp. 270-271), and are thus accounted for by this study. Since the Smart Farm does not require a land facility, this cost category and the associated depreciation costs from Buck et al. (pp.270-271) were not included. The study by Van Deurs et al. (2013) identifies the following cost categories: smart units, moorings, eider duck fence, navigational markings, transport and delivery costs, installation costs, working boat, small boat, SmartScooter, accessories and parts (p.24). Labor, insurance and interest costs together with boat maintenance, operation, and repair costs are also included (p.28). All of these cost categories were adopted into this study with the exception of the Smart Scooter, which was excluded owing to the small size of the proposed farm. Van Deurs et al. also included mussel transportation costs, but these were not included owing to the reasons discussed above. After the cost categories were identified from the above studies, the authors began to source the data.

Some of the data from the cost categories was produced by Smart Farm and was directly provided to the authors from their own pricing data (ie: SmartCat costs) and their expertise (average small boat cost). Other parties, including the Government of the Netherlands, the Yerseke Mussel Auction, and Global Aquaculture Insurance Consortium were directly approached by phone and email to provide salary, mussel sales price, and insurance data points respectively. Data was provided to the authors by email from each of these parties. Each party with whom the authors communicated 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. The authors completed this study remotely without in person meetings with any of the parties approached.

Pro rata analysis also took place to identify the boat operating costs of this proposed farm using the boat operating costs demanded by the farm depicted by Van Deurs et al. (2013). Public data available from the Government of the Netherlands was also used to generate information such as financing costs and licensing data. Using this data, the authors generated the findings discussed in the next section.

The assumptions of this study related to the conceptual framework, economic viability, market and production were also carefully analyzed and elaborated. These assumptions include 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 tons of mussels each farming cycle as per the manufacturer;
- A combination of more mature farming practices and an increase in the number of Smart units every five years would increase the total mussel production from 300 tpa to 700 tpa by the 20th year of operations;
- The employment of highly mechanized Smart Farm technology, by which mussels are cultivated and harvested efficiently with no direct hand labor;

The economic viability of this mussel farm depends on:

- Suitable environmental conditions to support mussel production;
- Access to Smart Farm equipment;
- A supportive regulatory environment for mussel farming in the Netherlands;
- Market factors such as the size and other parameters of existing mussel markets, both domestic and international, together with different available mussel forms and the sales price of mussels.

Given the need to exercise a holistic approach, the authors also gave careful scrutiny to the ideal location of this proposed farm, the regulatory landscape for mussel farming in the Netherlands, the most ideal relationship that could be developed with any future platforms depicted by the SPACE@SEA project, and mussel seed collection. These findings are discussed in the Results section below.

Smart Farm provided consultation to the authors throughout the completion of this study. As the authors proceeded, they noted that the farm could reasonably be expected to produce higher volumes of mussels over time as more mature and experienced farming practices are employed (see ‘Efficiency’ in Table 1). They also provided data on the amount of mussels that could reasonably be expected to be generated by the proposed farm over time. The authors subsequently completed profit calculations to generate Earnings Before Interest and Taxes (EBIT), Net Present Value (NPV), and Internal Rate of Return (IRR).

Results

In this section, the findings of this study are presented and discussed. Regarding the ideal location for this proposed mussel farm, it is evident that there are several guiding factors that must be considered. FAO (2023c) notes that presently all mussels farmed in the Netherlands are sold at the Yerseke auction. Given this, proximity to Yerseke for the purposes of mussel sales is ideal but not critical. Additionally, the permitting process would need to take into consideration the size of this proposed farm. The scale of the proposed farm at inception is 25 units but increases to 56 within twenty years. Each of these units is 137 meters long. 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 are much larger than the farm proposed in this study. As an example, the Smart Farm operation proposed by Van Deurs et al. (2013) had 800 units, required only three full time employees, yielded approximately 20,000 tons 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. Further, considering the proposed location of the multi-use platforms planned by the Space@Sea North Sea project is important to leverage the benefits of a symbiotic relationship with the associated projects. Ahrouch and Breuls (2020) depict the North Sea multi-use platform project as being in Dutch waters offshore from the Port of Antwerp (p.9).

While all of 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, defense 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 the Dutch government would assign to the proposed mussel farm.

Regarding developing a symbiotic relationship with business operations on future North Sea platforms, the authors chose to propose an offshore mussel 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 with any future offshore platforms, there does not appear to be any scenario where this proposed farm would be critically dependent on it. The proposed farm could have a potentially symbiotic relationship with these platforms in two ways. Were the mussel processing plant on the platforms proposed by Jak et al. (2020, p.5) to be developed, this plant could be used by the proposed mussel farm in lieu of or in addition to that offered by the Yerseke Mussel Auction in order to obtain a more competitive price. In turn, this could naturally increase the economic viability of these multiuse platforms. That said, the mussel purchasing and processing services of the Yerseke Mussel Auction may continue to prove important. Additionally, this proposed farm could have a potentially symbiotic relationship with floating multi-use platforms through the accessibility of these platforms, if permitting considerations were to place this proposed mussel 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 harboring, and repair services, provided that there was relative proximity. By adopting this model, the mussel farm proposed in this study would ensure its full viability apart from proposed multi-use platforms, and yet would be positioned to fully leverage the opportunities offered by them.

Another consideration that the authors analyzed related to mussel seed collection. The FAO (2023c) 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) noted how the mouths of the Rhine and Scheldt rivers (which are in the proximity of where this proposed farm may be located) offer nutrient and particle dense water (p.8). Finally, Buck et al. (2010) are highly positive about natural mussel seed accumulation in offshore applications (p. 266).

In addition to these considerations, it is important to note that offshore mussel seed collection could offer additional future profit opportunities for this proposed 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). In their own study, they projected that their mussel farm could yield a total annual revenue of €14.5 million, €4.4 million of which would come from selling mussel seed (p.19).

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 had a combined population of 760,000 common eider ducks (p.136), the authors judged the eider duck fence feature to be a feature necessary to have on hand. Regarding the harsh nature of the Dutch North Sea, 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 its 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 for storms.

This study advocates for an offshore mussel farm in the Dutch North Sea with an initial production capacity of 300 tonnes per annum (tpa) which can be realistically expected to reach 700 tpa in 25 years, based on more mature farming practices and the introduction of additional Smart Farm units. The details of aggregate anticipated production can be found in Table 1. ‘Efficiency’ in Table 1 represents the increase in mussel yield that is anticipated over time based on maturing farming practices.

Table 1

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 for this study was projected based on the selling price of mussels in recent years at the Yerseke Mussel Auction, which can be found in Table 2.

Table 2

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 through this project is summarized in Table 3. The major Capital Expenditure (CAPEX) categories for this study are as follows: offshore smart farm units, eider duck fence, moorings, navigational markings, transportation and logistics of equipment, a SmartCat (mussel boat), accessories and spare parts, and a small boat.

Table 3

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

** 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 cost of production for one kilogram of offshore mussels produced through this project is summarized in Table 4.

Table 4

Production Costs

Summary of cost of production for One Kilogram of Mussel	(Based on 300 tpa)
	Amounts in Euros
Labor 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**

As indicated in the above table, under the assumptions of the current model, a Dutch North Sea mussel operation of 300 tpa would achieve a favourable margin of € 0.9247 (72.5%) based on sales price (€ 1.2757) and costs of production (€ 0.351). The major Operational Expenditure (OPEX) categories for this model are as follows: labor costs, overhead costs, fixed costs, insurance costs, and financing costs. A detailed discussion on the components of Operational Expenditure is provided below.

Labor Costs

As per Statistics Netherlands (2021), the average yearly wages including bonuses for experienced workers in agriculture, forestry, and fishing (age: 50 to 54 years) is €35,810. Given the pioneering nature of this project, together with the need to hire someone who can captain the SmartCat, the authors deferred to hiring employees who are more experienced in this sector. This and other costs are displayed further in Table 5.

Table 5

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

Overhead Costs

To calculate the hours needed to operate the boats, 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, the authors 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, 615 hours for operating the boats each year was calculated. From here, the operating cost per hour was calculated. Based on the findings of Van Deurs et al. (2013) it is estimated that the cost of running the large vessel is 51 Euros per hour, while the cost of running the small vessel is 26 Euros per hour (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

The annual maintenance cost for the Smart Cat and other equipment has been set at 1 percent.

Insurance Costs

As per a preliminary quote the authors received from Global Aquaculture Insurance Consortium (2020), an offshore mussel growing operation would be insured against incidents 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, the authors 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%. The debt to total capitalization for this study is set at 40%, which is comparable to that of the aggregate mussel industry in Germany as reported by the European Commission (2019, p. 33).

Financial Projection

A summary of the projected financial results is presented in Table 5. Initial production of 300 tpa in the first five years was assumed 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 to us 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 relatively small and difficult to predict, owing to its dependence on open North Sea conditions, it was not included in the CAPEX calculations. Given these considerations, the authors chose 25 years of operation as the timespan for this study.

It is assumed that 25 mussel lines would each produce 12 tons of mussels in each farming cycle, which represents a reasonable scale that is financially viable under the model assumption. It is assumed that a combination of more mature farming practices and an increase in the number of smart lines every five years would increase the total mussel production to 700 tpa by the 20th year of its operation. Based on these projections, the study offers a feasible investment returning a positive Net Present Value (NPV) of € 3.5 million utilizing a 6.73% discount rate. The expected Internal Rate of Return (IRR) for this project is 19.78%, which indicates a relatively favorable return on a project of this nature. Since this is a time bound project, a terminal value has not been used in the above calculations. By approximately the end of the sixth year of operation, when the project reaches its Break Even-Point (BEP) (i.e. NPV equal zero), the selling price will be 1.5053 €/kg.

Discussion

This study projects relatively strong returns for a proposed Smart Farm that uses reinforced equipment to grow mussels 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 in the English Channel, it is important to acknowledge that the extraordinarily harsh conditions of this sea 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) to be helpful to further justify the technical viability of this farm. As part of this, it is important to note that the SmartCat, the largest expense associated with a farm of this type, can be leased to other companies in the commercial fishing sector for other purposes. Given that the SmartCat would only be used part-time in the project as depicted in this study, and much less in a smaller pilot project, the SmartCat could be leased to other operations on a meaningful basis in different scenarios. While a full investigation of the profit opportunities associated with leasing the SmartCat to other parties is outside the scope of this study, it is important to note that these additional profit opportunities in turn could offset the costs of the SmartCat significantly.

A second limitation of this study is the potentially high volume of mussels that would be harvested if it became a fully-scaled Smart Farm operation, and how this could be an area of sensitivity to existing mussel farmers in the Netherlands. FAO (2023c) 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 to this, a fully scaled Smart Farm on the scale of that depicted by Van Deurs et al. (2013) would. While this would naturally represent an opportunity for the aggregate mussel industry in the Netherlands, it could also be expected to generate some controversy from more conservative stakeholders. Accordingly, the small size of the operation depicted throughout this study is considered justified. Pioneers on this project may find it wise to content themselves with permit(s) only sufficient to cover the small-scale farm depicted in this study, in order to allay concerns about scaling up precipitously.

A third limitation of this study is that the fuel and boat operating costs were determined based on a previous nearshore mussel farm study (Van Deurs et al., 2013), owing to how the precise location of this farm cannot be known until permits are granted. Given this, fuel, boat operating, and labor costs can be expected to vary, depending on the farm's proximity to harbor. Severe weather conditions offshore and lengthy storms also have the potential to disrupt working conditions and to demand flexibility in worker availability, which could in turn present additional challenges.

A fourth limitation of this study has to do with the extent of the permits that most probably would be required. The Ministry of Agriculture, Nature, and Food Quality in the Netherlands (2021) communicated to the authors 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).

A fifth possible limitation of this study has to do with the length of time that permits would likely be in effect for a specified location on the Dutch North Sea. The Ministry of Agriculture, Nature, and Food Quality in the Netherlands (2021) directly informed the authors that the previous project documented by Jansen et al. (2016) which received temporary licenses for offshore mussel farming in 2011 (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 the lack of fixed offshore locations that can be guaranteed for the mussel farm depicted by this study. Simultaneously, it underscores the importance of being able to transport a mussel farm 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 as well.

A sixth limitation of this study has to do with how the mussel selling prices at the Yerseke Mussel Auction are strongly influenced by the bottom culture nature of most of Dutch mussel farming. FAO (2023a) notes that Dutch mussels circa 2000 sold for between USD 450 to 850 per tonne, depending on whether they were raised by bottom culture or the more highly valued rope culture. Given this, it is possible that the mussels projected in this study would sell at a higher rate than is projected. With that said, Smart Farm highlighted how many Dutch consumers have a traditional preference for the distinctive taste and quality of bottom culture mussels (B. Aspoy, personal phone communication, Feb. 4, 2021). Given this, investors in this project have reason to be optimistic about their returns, while they have reason also to avoid being overly confident about sales in the Dutch market.

Conclusion

This study found an IRR of 19.87% and an NPV of €3.5 million on a 25-year offshore mussel farm in the Dutch North Sea that uses the Smart Farm approach. This is particularly favorable when compared to the offshore mussel financial feasibility studies analyzed in the literature review. Given that the proposed farm in this study 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 favorable to the 4.9% and 9.6% return on investment found by Bartelings et al. (2014). 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 increasingly Europe is moving beyond this.

The IRR of this study is also favorable 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 labor is a 'main cost component' for each methodology (p.95). The production costs per kilogram to farmgate price per kilogram of the ration in this study (€ 0.351: € 1.27) stands at significant variance to the farms employing conventional methodologies, and adds credence to the fully mechanized and offshore nature of this farm.

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 economic opportunities and beyond on the aquatic frontier in a measured, tempered, and evidence-based manner. Future research should focus on supporting and coordinating with Dutch regulators in order to give a greater degree of predictability to investors regarding precise locations and durations of permitted offshore mussel farms, in turn, increasing investor confidence. It would be ideal for offshore mussel farmers to depend on designated areas of the Dutch North Sea set aside for their farms in a manner that is comparable to what is presently enjoyed by wind farming companies. Future research should also focus on assessing the economic viability of other aspiring or actualizing offshore ocean businesses, in addition to mussel farming, 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 offshore ocean economy taking on a momentum all of its own, with a plethora of possible benefits across a multitude of domains.

This study helps to establish that the investment opportunities of 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

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 2

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

640640

Table 3

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

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

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

641641

Table 4

Production Costs

Summary of cost of production for One Kilogram of Mussel	(Based on 300

	tpa)
	Amounts in Euros
Labor 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 5

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 reasonably profitable.
- An offshore SMART Farm can generate an IRR of 19.78% and an NPV of €3,479,178.
- Mussel farming can have a symbiotic relationship with offshore multi-use platforms.
- SMART Farm technology is mature and offers meaningful scalability.
- Proliferation of offshore mussel farms can help meet many of the United Nations SDGs.