CROWN ESTATE SCOTLAND

Economic Feasibility Study on Seaweed
(Cultivation and Supply Scenario)

March 2021

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EXECUTIVE SUMMARY

Seaweed farming in Scotland is at the early days of what is, globally, becoming a sector which has significant growth opportunities involving coastal communities. In Scotland this sector has seen an expansion in 2020 from what was mainly experimental/pilot sized farms. A number of new farms are due to be harvested in 2021 with seaweed being sold into a range of markets. Stakeholders across the supply chain have been engaged to develop an understanding of, and to confirm, the logistical, market and financial opportunities and challenges. Engagement took place (one to one conversations) with 35 organisations working across the seaweed farming supply chain, to discuss costs, prices, markets, techniques, opportunities and challenges.

A cost benefit analysis (CBA) model has been prepared from the desk-based reviews, research and stakeholder engagement, for a number of scenarios, involving seaweed farms of different scales and integration, in terms of the supply chain. The costs were discussed with farmers and infrastructure suppliers, and then scaled up for different sizes of farm. The CBA then assigns prices for outputs from farms (fresh/wet, processed) and estimates the payback period, internal rates of return etc. Prices have been adjusted for the scenarios to provide payback periods less than 10 years, and if possible/realistic, within a three-year period. This approach was used to identify target costs and prices to understand the sector and market potential, rather than stating that certain types of scale, supply chain model etc are not viable.

The CBA baseline results and sensitivity analyses indicate that there are a number of viable scenarios in terms of achieving a payback of investment for seaweed farms from 8 to 32 hectares, within 3 or 5 years – that is, if the prices shown for wet and dry seaweed would be acceptable to buyers. The prices that have been identified from stakeholder discussions and desk-based research as being a requirement for viable business models indicate that for smaller farms (e.g. circa 8 hectares) there may be challenges in getting seaweed sold to the market if there is not an added value, processing step involved, e.g. targeting sales to human food markets. For farms of this scale the CBA has indicated that prices of more than £1,000 per tonne of wet seaweed would be required for a payback within a 3-year period. This is a price level which might not be achievable without added value being incorporated in the business model. Sensitivity analysis is a key part of the analysis, with a range of costs and prices changed to identify the impacts on financial viability. A number of points are made below related to this, comparing the debt financing scenarios (70% bank lending for capex) only, for consistency:

- Boat costs – boat purchasing versus boat leasing have a significant impact on viability, the former providing more viable outcomes.
- Seaweed yields from seeded line – the baseline used was 6 Kg/metre. Increasing this to 8 Kg/metre significantly reduced the payback period for all scenarios considered.
- Increasing the leasing cost charged (a potential illustration of how this could be approached by Crown Estate Scotland in the future) – the baseline used was £0.02/metre of seeded line. Increasing this to £0.20 per metre increases the payback period by circa one year for most scenarios considered.
- Reducing seeded line costs from £2.50 to £1.00 per metre reduces the payback period significantly across six of the seven scenarios considered by 2 years.
- Combining a lower seeded line cost (£1.00/m) with reduced prices for wet/fresh outputs, by circa 20%, secures paybacks within 3 to 5 years for most of the scenarios.
- The combination of reduced cost seeded line (£1.00 per metre) with a higher yield (8Kg) and reduced sales prices has a significant impact. For example, a scenario involving eight hectares being farmed has a payback period of 3 years, with a price earned (by the farmer) for wet seaweed of £1,200 per tonne – this compares to a price of £1,700 per wet tonne in the baseline (to achieve a viable business mode), a price which might be too high for current processors/distributors.

Conclusions

Seaweed farming is already happening successfully across the world, with increasing levels of interest and developments taking place in the North Atlantic, which is becoming a geographical area of increasing interest for a range of international and national investors.

The size of farms considered in this project ranged from 8 to 64 hectares (growing areas) with a number of opportunities identified for returns on investment. Investment in farms will need to be associated with the development of processing infrastructure, to get products to market. A key question is what type of infrastructure and what are the market drivers associated with this? A challenge with Scotland or rest of UK (rUK) markets is the visibility of seaweed as a food item, although this is changing, slowly. Market development efforts will be key to supporting the sector to grow.

As well as the challenge associated with markets is the availability of processing infrastructure that can add value and enable higher returns on investment. The more value to be added, comes with the potential for this to involve more capital investment, which in turn requires the feedstock to justify this investment. This is an important aspect of future development, to understand what type of sector the country would be supportive of in terms of its growth i.e. will both large, mega-farms and smaller farms be accepted, or will more, smaller-scale farms be the model that wins out in the future. In the case of there being many small farms established, the Scottish Shellfish Marketing Group has developed a model which could be of value, involving a collaborative approach for the development of standards, access to markets (e.g. retailers/supermarkets) and processing infrastructure.

Collaborative working has been identified as an aspect of supply chain development which is of interest to the farmers and the existing processing infrastructure (developed to date on the basis of wild harvested seaweed). A challenge associated with this will be the different cost structures associated with producing seaweed from farming activities, compared to wild harvesting, the latter having a much lower cost associated with it (at least ten times lower).

Engagement with the fish and mussel farming sectors took place, and there was little opportunity found among the participants, in particular with the former, in terms of collaborative working, or for this to be in a position to act as a market e.g. seaweed is not considered to have high enough protein levels to substitute for existing fish-feed products. There may be opportunities for work boats associated with mussel farming to be employed in the installation, support and harvesting of seaweed, however, this has still to be determined. Seaweed farmers were of the view that the types of workboats used by the fish farming sector are too large and expensive for seaweed farming.

Some interest was expressed in seaweed cultivation as a potential diversification tool for fishers, although the same challenges are likely to exist, as above, within the aquaculture sector, including the suitability of boats to be used during installation, support, and harvesting.

The potential for co-locating seaweed cultivation with shellfish aquaculture or to act as a mitigation tool, to improve the environments surrounding other aquaculture activities was considered and discussed with stakeholders, however, this approach, known as Integrated Multi-trophic Aquaculture (IMTA), was considered to have the potential for only marginal improvements (e.g. in terms of nitrogen fixing) with negative impacts in terms of the potential applications for seaweed grown for such purposes i.e. it was considered that seaweed farming should be considered as an activity which has the potential to produce high quality products first and foremost, with environmental benefits underpinning this, e.g. in terms of improvements to ecosystems and potentially in terms of carbon.

The growing interest in developing high value markets, will require an increase in either the utilisation of existing processing infrastructure and/or the development of new infrastructure. The latter is particularly the case with respect to innovation, for example, to use seaweed as a new feedstock for new packaging products, and/or increasing quantities of food and other high value products. This infrastructure will need to be developed in Scotland if there is demand and interest in developing added value products, with high levels of innovation e.g. that are associated with new, low carbon products in the future. This type of innovation has the potential to create demand for seaweed farming, and support a healthy, growing sector in the future.

The costs of seaweed farming are significantly higher than those for wild harvesting. It is therefore the case that if the increasing demand for high value products can be met by increased capture of wild grown seaweed this will prevent the growth of the seaweed farming sector.

Recommendations

Stakeholder engagement and research has identified a number of opportunities for supporting the growth and sustainable development of a seaweed farming sector in Scotland, as summarised below.

- Market development work and collaboration across the supply chain: The example of the Scottish Shellfish Marketing Group should be considered - where co-operative and joint venture partnerships can open doors to the retail sector (e.g. supermarkets), standards can be developed, and barriers associated with investing in costly processing infrastructure can be overcome through pooled investment approaches. The benefits may be particularly significant in the seaweed sector by pooling knowledge and services at the inputs side to provide supply capability and scale.
- Guidance on setting up seaweed farms and the licensing process: The development of mapping tools to show where the important fish stock areas are, to avoid conflicts when selecting sites. A big issue is the potential for conflict with the fishing industry.

- Licensing timescales: A service with a faster response time than is currently the case would be welcomed, including additional support and hand-holding.
- Crown Estate Scotland leasing costs: The current approach to leasing, which has been described positively, should continue to be employed in the short-term i.e. with the industry just starting to find its feet leasing cost levels should not be set at levels which are a prohibitive and a barrier to the growth of the sector.

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1.0 INTRODUCTION

1.1 Background

Seaweed farming in Scotland is at the early days of what is, globally, becoming a sector which has significant growth opportunities involving coastal communities, and which has the potential to provide high value products which are grown following sustainable practices.

Seaweed farming in Scotland has seen an expansion in 2020 from what was mainly experimental/pilot sized farms. A number of new farms are due to harvest in 2021 and sell into a range of markets.

The seaweed processing sector has been established now across a number of locations in the country, with significant capital investment, to process seaweed collected from wild harvesting. In parallel, work has been undertaken to develop a number of high value markets, ranging from human food products, nutraceuticals, agricultural markets. In addition, there has been a number of high price markets developed for the cosmetics and drink sector, but so far, requiring a small tonnage of seaweed to be supplied.

The feasibility study carried out, and summarised in this report, had the following objectives:

- To identify and engage with stakeholders across the supply chain involved with delivering a viable, sustainable seaweed farming sector.
- To investigate and confirm the prevailing logistical and financial circumstances and opportunities through engagement with the stakeholders identified.
- To describe scenarios that could contribute to a durable and commercially viable seaweed business supply chain.

This above has been considered along with a detailed financial prognosis, referencing the alignment of this with requirements for continued social licence and scope for growth.

1.2 The Methodology

The team involved in the delivery of this project included SAMS and IMANI, responsible for delivering the 2019 project "Seaweed Farming Feasibility Study for Argyll & Bute". The methodology was developed to build on this previous work and involved the following tasks:

- Desk-based review focussed on identifying key stakeholders and to structure a range of questions for the subsequent engagement.
- Engagement with the stakeholders (farmers, infrastructure providers, processors, seaweed buyers etc) to discuss activities, opportunities, costs, potential income streams, concerns, limitations etc.
- Descriptions and details of potential, different development types (supply chain models), scales of farm and end products.
- Cost Benefit Analysis (CBA) and scenario development using the cost and income data secured from the stakeholder engagement and desk-based research undertaken. Sensitivity testing is carried out to show how significantly viability changes when key criteria are altered e.g. the cost of seeded line, the separation distance of long-lines (impacting installation costs and yields) etc.

The following sections provide the results, conclusions and recommendations from the above work.

2.0 DESK-BASED REVIEW

A desk-based review and analysis was undertaken using combinations of key words such as "Scotland, seaweed, farming, etc". This identified a number of stakeholders across the supply chain for engagement in Scotland and across Europe, as well as identifying pertinent research and market publications. In addition, a number of online marketing and sector videos, podcasts, and recent developments were identified from this work. A summary of selected key sources identified is provided in Table 1.

In addition to the information sources listed in the table, a number of additional sources have provided key information in terms of developments in the seaweed farming sector, in particular in the North Atlantic and Europe, as summarised below:

WWF, the Bezos Earth Fund and Finance Earth[i]: In August 2020, the Bezos Earth Fund awarded $100 million (US Dollars) to the seaweed farming sector, with projects involving the World Wildlife Fund (WWF). Also in August 2020, a $850,000 (US Dollar) investment was announced for Ocean Rainforest (Faroe Isles), to accelerate growth of offshore seaweed production for the benefit of people, communities, and climate gains. The company, earlier in 2020 announced the closing of an investment round to enable the scaling of seaweed farming operations in the North Atlantic, which was led by WWF.

Online news & documentary articles: CNN and the Financial Times (FT) have described existing seaweed farming operations and also identified the plans for growth of seaweed farming in Norway, with over 100 farms now licensed (2020), and harvests of kelp projected to increase by 100% in 2021, compared to 2020 (when 150 tonnes of wet kelp was harvested).

Table 1. Summary of selected desk-based review sources

Publications / Sources	Descriptions – Areas of Interest
Argyll and Bute Council, "Seaweed Farming Feasibility Study", 2019	The case studies were considered and informed subsequent stakeholder engagement discussions. The capital and operational costs (capex and opex) were reviewed/revised and along with other cost and price data secured online were used for engagement with stakeholders.
Seaweed for Europe, "Hidden Champion of the Ocean – Seaweed as a Growth Engine for a Sustainable European Future", 2020.	Describes the economic potential of an expanded seaweed market in Europe, stating that this could be worth €9 billion (Euros) in a decade - also that the European seaweed industry could create up to 115,000 jobs by 2030 and deliver significant environmental and health benefits. It states that: *"targeted investment, regulatory streamlining, increased research and development of new applications based on seaweed will be needed to unlock this opportunity."*
Energetic Algae ('EnAlgae'), "Best Practice Guidelines for Seaweed Cultivation and Analysis Report WP1A5.01, 2016":	Wide ranging report, with information provided in a simple format on the licensing and permits steps required, in a Northern Ireland context.
The NAFC, "Seaweed Cultivation, Manual, Shetland Seaweed Growers Project", 2014-16	Growth and yields information (s5.5, growth and yields of cultivated kelp).
The Marine Institute (Ireland), "Marine Research Sub-Programme (NDP 2007-'13) Series Development and Demonstration of Viable Hatchery and Ongoing Methodologies for Seaweed Species with Identified Commercial Potential", 2013	Although now a number of years old it provides set up cost and commercial value information which is useful for comparative purposes.
Irish Sea Fisheries Board, "A Market Analysis towards the Further Development of Seaweed Aquaculture in Ireland", 2011	Although now a number of years old it provides set up cost and commercial value information which is useful for comparative purposes.
University of Wageningen, "A Triple P review of the feasibility of sustainable offshore seaweed production in the north sea", 2013	Although 7-8 years old now, there is useful information on European markets, costs and incomes at that time.

The desk-based review has informed the development of costs and incomes, the range of market opportunities etc. The Argyll & Bute study used a feasibility framework to interrogate the feasibility, strengths and weaknesses in the nascent supply chain for seaweed farming and provided indicative set-up costs which were further developed and used for engagement with stakeholders – to seek feedback on their robustness, and to amend these where required.

This work has fed into the development of questions tailored to specific types of stakeholders as summarised in Appendix A.

For the CBA work undertaken, a number of stakeholders agreed to provide a view on costs provided to them and the costs used in the CBA work reflect the views provided.

3.0 STAKEHOLDER ENGAGEMENT

3.1 Overview

Extensive stakeholder engagement has taken place, with current and future farmers, harvesters (of wild seaweed), installers (of infrastructure) processors and sellers of finished products. In terms of the overall number engaged, 45 potential companies and organisations were identified as potentially valuable stakeholders and 40 were contacted. 35 of the companies/organisations contacted responded resulting in 32 conversations through video/phone calls with three responses by email. The split is summarised in the table below, in terms of where the stakeholders fit in the supply chain.

Table 2. Summary of organisation types engaged with

Organisation Type	No. Engaged
Intermediary, with R&D, design and/or hatchery potential	7
Mooring deployment and maintenance	4
Growing, Maintenance, Harvest, Storage and Processor, for Offtaker (e.g. drying)	5
Processing for human food, pharma, packaging or animal feed	4
Processing seaweed for bioagronomy	1
Third party processor, packer and distribution	1
Full supply chain – farming and/or wild harvesting, through to human food sales.	4
Aquaculture – fish farming organisations	2
Shellfish farming	4
Seaweed processing technology providers	3
TOTAL	**35**

The key areas covered in the engagement with the above organisations were:

- The size of farms
- Costs of farming
- Markets and prices
- Intermediary support – the need
- Control & collaborative working
- Processing and infrastructure
- Leasing and regulatory considerations
- IMTA

3.2 Summary of Engagement Results

3.2.1 Types of seaweed for farming

The seaweed farming opportunities identified and discussed were mostly concerned with kelp species, with saccharina latissima identified as the most highly valued, although others are also of interest, for example, ascophyllum nodosum. Although not identified to be of interest for farming in a Scottish context, it should also be noted that dulce, currently wild harvested in Scotland is farmed in a land-based system at a site in Canada (Charlesville, Nova Scotia), thought to be the largest land-based seaweed farm in the world, operating on a 60-acre site, with 20 acres being used for operations, the infrastructure consisting of clay ponds with liners.

The cost benefit analysis has been carried out on the basis of capital and operational costs using longline systems, with market/sales prices used to demonstrate what payback periods and returns on investment result from these.

3.2.2 The size of seaweed farms

A total of 4 organisations were engaged that have plans to harvest seaweed in 2021, with another 4 looking to develop a range of different types and sizes of farms in the near future. The 4 with plans to harvest in 2021 are developing these in the range of 2 to 8 hectares (growing), with a significantly larger area to account for deployment infrastructure. Some key points from these discussions are listed below.

For harvesting in 2021, the sizes of farms are:

- 2 to 3 ha initially, moving to 6 ha
- 3 to 4 ha to be farmed from a 15 ha site. Producing wet seaweed initially with plans to dry this in the future
- 1 ha, with 30 ha planned on an 80 ha site
- 3 to 5 ha of growing on a 13.5 ha site

Other developments or considerations which are in the early stages, or going through a research phase initially, involve the potential for the following:

- Research funding in place with the aim of developing 3 small farms growing inter-tidal seaweeds that already grow in such places – not kelp.
- 15 ha growing farm in a 30 ha site
- A number of larger farms, in various locations– 500 ha up to 1,000 ha (kelp and other species)

3.2.3 Costs of farming

The costs developed in the desk-based work were commented on by a number of stakeholders, including two farmers and one deployment/installation company. The costs shown in the CBA have taken on board the feedback and are considered to be a reasonable estimate, by these stakeholders, at the time of writing.

Key challenges identified by farmers were:

- Costs of seeded line
- Workboat leasing costs
- Deployment and harvest costs
- Design – need to better understand the pros and cons of different methods, which have impacts on costs

Seeded line can be procured from a number of sources and the following organisations have provided input in terms of this potential:

- SAMS, Scotland
- Hortimare, Netherlands
- SINTEF, Norway
- Islander Kelp, Northern Ireland

The 2019 Argyll & Bute report provided a cost level of £5.00/metre which stakeholders indicated was a major concern. The CBA has been carried out using a baseline of £2.50 per metre, which with changes to production methods, competition etc is considered to be a viable price. It is also understood that there is potential for this to be significantly reduced in the near future as new methods are approved, and demand increases.

In terms of workboats different farmers are considering a range of options, with leasing costs considered to be a significant barrier. The purchase of boats, or the collaboration with local fishermen is considered to be an important step in securing a more viable outcome.

Farmers have shared information on investment costs for the installation of farms, deploying the harvesting and processing equipment. Processors, sellers and technology providers have shared information on costs of production, cost of goods sold (COGS), production costs etc. More commentary on this and how the data has been used in the CBA is provided later.

3.2.4 Markets and prices

Wild harvesting companies in Scotland and the rest of the UK (rUK) are supplying high value processed (frozen/dried, milled etc) seaweed products for the human food markets, selling online and through retail outlets. The types of prices earned for food markets are easily accessible and found at many retail, online sources. Less visible are the prices earned in a range of international markets for dried and milled seaweed e.g. sold as animal feed supplement, soil enhancement, alginate, cosmetics and nutraceutical industries.

Significant variations in prices are paid by these markets. The dried and milled product prices earned vary significantly depending on which of the above markets the seaweed is being sold into. For example, £1,000 to £3,000 per tonne for dried product appears to be generally available, with significantly higher prices paid for limited quantities of such products. In terms of prices for wet seaweeds a number of stakeholders have indicated that between £500 to £1,000 per tonne could be paid to farmers.

Stakeholders in the agricultural and aquaculture feed markets have been engaged through the project and at this point in time the opportunities mainly appear to be those associated with the former, where in particular there may be significant opportunities to use seaweed as a feed supplement (to improve animal health). The limited protein content of seaweed may make it of limited interest to the aquaculture feed sector in the near future (as well as the animal feed market).

There are also significant efforts being made to develop packaging products from seaweed, which have the potential to come to the market in the near future. The prices that would be paid to farmers for this type of development were not divulged.

It should be noted that viable opportunities associated with biofuels were not identified in the stakeholder engagement as an opportunity that is currently available. This was discussed with a number of stakeholders who indicated that they had not been able to identify a commercial case for this at the moment.

3.2.5 Intermediary support – the need

The most common feedback was with respect to the importance of an intermediary role concerned availability of an affordable seeded line service. However, there was a diverse range of views on the value that an intermediary can provide to the sector. One stakeholder commented that they felt it is important that in the future there is a government-backed/supported seed/nursery service, where the quality, provenance and costs associated with seed are controlled and trusted by the sector.

It was commented by another stakeholder that an intermediary to assist with the marketing of seaweed products could be a fundamental driver of demand and opportunity for the farmers. Although the Scottish Shellfish Marketing Group was not specifically mentioned in the discussion it is an example of a successful intermediary which has allowed common standards to be worked to, with retail customers available to small producers that otherwise would have found this step (accessing supermarkets) too difficult.

It was also commented that there we would be value in the development of the following:

- Mapping tools to show where the important fish stock areas are, to avoid conflicts when selecting sites. A big issue is the potential for conflict with the fishing industry.
- The process of engaging with organisations like Marine Scotland (licensing applications) has been described as time consuming, with, typically 10 days response times to queries. A service which would provide speedy assistance and hand-holding would be welcome.

3.2.6 Control and collaborative working across the supply chain

Almost all stakeholders are interested in different aspects of collaborative working. Examples of this are summarised below:

- Collaboration by a number of farmers to enable them to access high value food and other markets.
- One future farmer's business model is very much focussed on working with small communities to develop the farming of seaweed species already established and growing naturally in the local environment.
- A number of existing processors (of wild harvested seaweed) would be interested in working with farmers to develop supply chain models that would allow them to secure increasing levels of supply (wet and dry), while providing the farmers with viable pricing structures.
- One fish farming company indicated that it might be interested in establishing a seaweed farm as part of a future fish-farming licensing process.
- There was interest from a farmer in the potential for using an existing site and infrastructure from previous mussel farming (incorporates a large shed that was historically used for seaweed drying).
- Fish farming boats are too large and expensive for collaborative purposes with seaweed farming (at the scales discussed in this project). Developing joint venture (JV) agreements with mussel farmers has been considered, but has been too complicated to resolve, although the deployment of mussel farming boats may still be a good opportunity.

Some players are currently seeking to develop specialised products and/or to potentially have supply chain agreements with their suppliers. These may involve large tonnages (large farms) being processed and therefore the question of how the seaweed farming sector is organised is a part of this i.e. will Scotland in the main have many small farms, or a small number of large farms, or both. The CBA (Section 7) in this report is neutral in this respect, but provides scenarios of different scale and discusses costs, prices and viability associated with these.

Section 5.3 comments on how the development of an aggregator/intermediary could potentially facilitate access to processing infrastructure and markets for many small farms. The CBA outputs later indicate why, to have the development of such processing infrastructure and market development, there needs to be seaweed production at scale.

3.2.7 Processing Companies

The types of processing companies engaged with are summarised below:

- Seaweed companies with a fully integrated supply chain – currently processing farmed and wild-harvested seaweed.
- A third-party processor (England) which accepts partially processed seaweed in IBCs then dries, mills, packages and distributes these to the market on behalf of the supplier.
- A processor (England) currently receiving dried seaweed (not kelp) in flakes and after further processing is then distributing a high value agricultural product around the world. They are now interested in the potential for developing a kelp-based product.
- An animal feed company carrying out trials for the use of seaweed in animal feed.
- A start-up company undertaking trials to produce a range of high value products, including food, nutraceuticals and packaging (film and card).
- Technology providers (China) – contacted to understand the range of costs associated with purchasing shredding, drying and milling equipment.

The above engagement has identified that in Scotland the drying infrastructure available has involved significant capital investment, however, there is capacity and interest, in the main, for further processing of farmed seaweed, if the price, quality and condition of material (e.g. should it be wet or dried) can be agreed. Because of the scale of capital investment (multi-million pounds in some cases) it will be a challenge for small-scale organisations/companies without financial backing to make a business case for investing in processing infrastructure. However, this is where a collaborative approach (the Scottish Shellfish Marketing Group example mentioned earlier) could be of value, or where a phased approach is developed. There are a number of ways in which this could work, and these are modelled later in the CBA, and described in the scenarios.

3.2.8 Leasing and regulatory considerations

A number of companies commented that leasing costs for seaweed farming should be based on a stand-alone pricing model different to others currently in place, for example different to that used for mussel farming which is generating significantly higher returns. Some comments:

- Until the potential of seaweed farming is proven a nominal leasing fee should be adopted e.g. £200 annual fee.
- Future leasing costs should be informed by the value of the crop harvested.

The CBA described later considers the above, and comments through sensitivity testing on how variations in pricing impact on viability and rates of return.

3.2.9 Integrated Multi-trophic Aquaculture (IMTA)

A significant area of sea needs to be planted for marginal benefits in terms of providing compensation for some impacts associated with the aquaculture sector. For example, Adams et, 2016, commented:

> *"In terms of sequestering 10% (as a nominal value) of the nitrogen from a 1,000 tonne salmon farm, this would require approximately 10 to 13 ha of seaweed cultivation."*

Stakeholder engagement on IMTA eventually focussed on messaging, and the idea of seaweed as being a remediation solution did not come across as appealing – benefits also likely to be marginal. The prevailing view was that the seaweed sector should be focussed on the delivery of high-quality products which can generate the best possible margins and returns, rather than be seen as a remediation solution. The messaging and perceptions of future consumers are important. Just as the mussel farming sector communicates a strong, local community and low impact sector, the seaweed farming sector can learn from this e.g. "rope grown seaweed" delivering nutritious, high quality products, in an environmentally friendly way. However, even where IMTA could be used n the future, the comment was made that the fish-farming sector, for example, was increasingly improving its efficiency in terms of nutrient release to the surrounding environment, compared with 10 years ago.

In addition to the above it should also be noted that the increased effort and infrastructure complexity associated with *seaweed + fish farming* and *seaweed + mussel farming* was not viewed positively by the stakeholders engaged from these sectors.

4.0 SOCIAL LICENCE AND COMMUNITY ENGAGEMENT

Social licence is an industry-coined term (Gehman et al., 2017) relating to the relationship that industries have with local communities based on the social and environmental impacts of operation (Gunningham et al., 2004; Moffat et al., 2016). The 2019 Argyll & Bute report described the concept of social licence in relation to the aquaculture where it is has gained significant traction in recent years, particularly within the finfish industry. There is currently limited peer-reviewed literature specifically on the social interactions that commercial scale seaweed production has or is likely to have in Scotland and elsewhere in Europe. However, of particular importance to seaweed cultivation at this stage, there is evidence showing that not having social licence can reduce the availability of space for expanding and/or establishing new sites (Strand & Bergh, 2017).

Up to 2021 the seaweed cultivation sector has been limited to small and pilot-scale farms in Scotland, primarily for community purposes or research. In general, and as shown in this body of work, seaweed cultivation will need to be spatially extensive in order to be economically efficient. Therefore, it is likely that new and existing seaweed farms will need to be significantly larger than pilot-scale farms, with greater interaction with other marine users. However, it is also clear that there is more to gaining social licence than resolving sectoral conflicts (e.g. through planning processes) and social acceptability will likely be a contentious issue in the mid- to long-term development of the sector.

Related to the above, at an event held in February 2020 during the Scottish Seaweed Industry Conference at SAMS[ii] the views of a selection of stakeholders (25 participants) on topics such as the preferred size of farms, ownership models, influence of the industry and location, tec, were that:

> *"...there was no strict consensus among the participants: visions vary from small to large size farms, from local focused industry to international and from coastal to offshore location. However, participants excluded the possibility of strict large companies and multinational ownership."*

At a commercial scale, seaweed production will have environmental interactions, both positive and negative, with the surrounding environment (Campbell et al., 2019). Industry, lobbying organisations, and individuals are aware of the environmental impact and can therefore use arguments based on such impacts to justify or oppose enterprises or industries. Social licence practices will likely be needed and utilised by the seaweed industry to manage the social risk of opposition to expansion, by developing communication and best practice strategies, and for communities and other users of the marine environment to negotiate beyond compliance behaviour from the industry.

A formal method of gauging societal perspectives was not undertaken within this project. However, from the limited stakeholder engagement work carried out in coastal areas to date, large, internationally-owned seaweed farms have been identified as the least desirable model for seaweed cultivation development in Scotland. Instead, providing community benefits and local jobs were expressed consistently among stakeholders from across the prospective supply chain. Furthermore, there was a range of "ideal" sizes described for the prospective growth of seaweed cultivation and it is clear that this may be influenced by societal and/or regulatory factors moving forward.

5.0 INTERMEDIARY ROLES

5.1 Intermediaries in the seaweed industry

The 2019 Argyll & Bute report clearly recognized the significant role of intermediary organizations in developing the seaweed industry in what is an unintegrated supply chain. Currently, intermediaries play an important operational role, primarily through the provision of seeded line. However, other intermediary roles may play a part in the short-term development of the industry, including the role of an aggregator to amass a favourable amount of biomass for processing or to increase the social acceptability among Scottish communities.

5.2 Seeded line

Twine seeding is currently the most reliable method for seaweed cultivation of the kelp species. The provision of seeded twine, whereby seaweed is grown in a hatchery/nursery setting for planting out on larger rope infrastructure, is a critical aspect of seaweed cultivation and is used consistently across European farm sites on various styles of farm infrastructure. However, the procurement of seeded line represents a significant operational cost to cultivators on an annual basis (further discussed in Section 3, Stakeholder Engagement and Section 7, Cost Benefit Analysis.

As stated above, effective seeding of macroalgae currently requires an initial nursery/hatchery phase, which maximises the survival of early recruits by optimising the conditions for their growth from microscopic spores to macroscopic juveniles. However, it is noted that there remains to be significant innovation in the provision of seeded material and a newer method, referred to as direct seeding, may provide a more cost-effective alternative to the traditional twine seeding methodologies.

Direct seeding dramatically reduces the hatchery/nursery phase required for twine seeding by spraying or embedding juvenile seaweed directly onto rope, ribbon, or other substrate that is then immediately outplanted onto farm infrastructure. This both reduces the labour associated with the production of seeded material and the effort, including boat time, involved in deployment, which in turn reduces the operational costs associated with cultivation. The costs included in the baseline cost benefit analysis are based on the current cultivation methodologies (i.e. twine seeding), however, the potential lower cost associated with direct seeding is addressed in the sensitivity testing, to demonstrate the impact on the viability of seaweed farms. It is possible that the industry will benefit from the availability of direct seeded materials in the near future.

5.3 Creating an intermediary to act as an aggregator for smaller scale farmers

Large scale farms and businesses, backed by investment capital, will be more readily able to develop integrated, sophisticated supply chains, than most small, community-based farmers. The former will be able to invest in the required processing infrastructure to gain added value in the marketplace and generate maximum return on investment.

Smaller farmers will be able to process to add value as well, as described in Section 7 (the CBA), but in most cases not to the same level. However, a means of such organisations collaborating has been touched on previously with respect to the type of model that the Scottish Shellfish Marketing Group has set up. A model similar to this could enable small-scale farmers, often operating in remote locations, to pool their resources, and to develop logistics and processing infrastructure, as well as to access markets that otherwise would not have been available to them (e.g. retailers/supermarkets).

This may be desirable from a social licence point of view, and for building significant volume through small enterprises – collaboration could be considered in setting up supply capability as well as marketing. Alternatively, small scale farming could develop through direct, closely integrated value chains where this feeds into the food sector, or through direct supply contracts, but current growth under this model has been ad hoc and limited to date.

6.0 DEVELOPMENT TYPES: SUPPLY CHAIN SCENARIOS

6.1 Overview

The development types and supply chain models in the CBA are based on the following:

- What is happening in the seaweed farming and wild harvesting sector at the moment.
- The costs of processing equipment to produce the highest value products.
- The types of organisations interested in developing seaweed farms.
- The demand in the market-place for different types of seaweed products.

In 2020 there were two experimental/pilot scale farms with seaweed being harvested. This will increase with at least a further three commercial farms producing seaweed in 2021. In Scotland, currently, there are a number of processing sites established for the drying and processing of different seaweed species wild harvested from the shoreline, with excess capacity. There are also processing sites in England accepting seaweed from various international locations. These factors have fed into the development/scenarios described in the next sections. However, to assist in understanding the basis for the costs used in the development scenarios, describes the configuration of a seaweed farm, the associated yields and indicative costs for the infrastructure.

6.2 The configuration of farms – infrastructure and potential yields

The following, Figure 1 and Figure 2 show two potential options, among others currently used around the world, for farming seaweed. There is already significant bodies of research and data available on such methods, and it is not the objective of this report to review the pros and cons of these. The CBA described in Section 7 is based on installing, maintaining and harvesting from a farm configured in line with Figure 1.

The yields associated with a farm of this nature are typically described in terms of Kg of seaweed per metre of seeded line, and such lines will be arranged in such a way that maximises this yield, without entanglement of the lines by locating them too close to one another. In the CBA analysis for this report the separations considered were 3, 4 and 5 metres. Stakeholders have commented that going less than 3 metres is likely to cause issues, as lines will become entangled, harvesting methods will be compromised, as will quality.

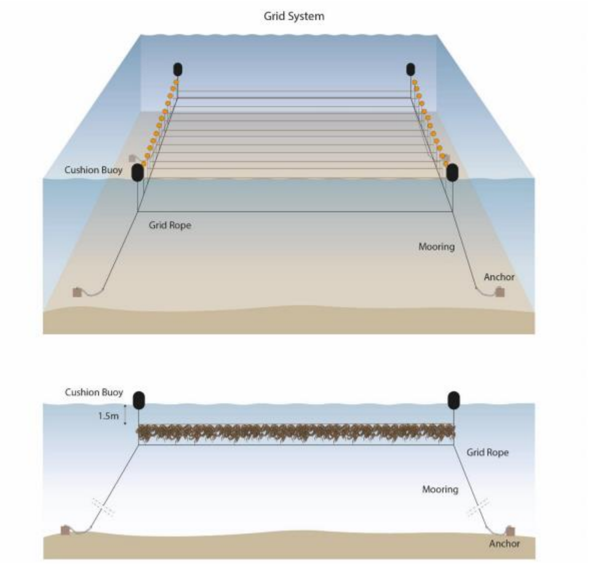

Figure 1. Double header system and grid-based longline system

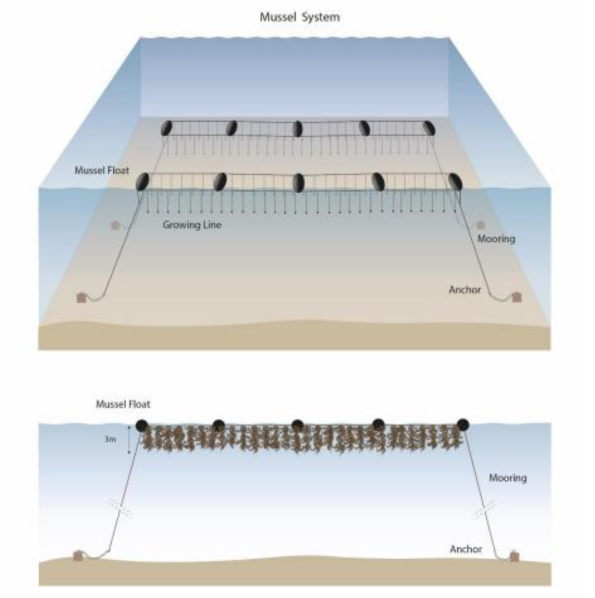

Figure 2. Pair of double-header rope mussel systems used for seaweed cultivation.

The yields associated with the longline configuration modelled in the CBA are summarised in the table below.

Table 3. Illustration of how the yield of seaweed has been calculated and used in the CBA

Criteria	Value
Length of lines	100 m
Separation of lines	4 m
Lines per ha (approx.)	25
Length of seeded line per ha	2,500 m
Yield per metre	6 Kg
Yield per Hectare	15,000 Kg

6.3 The development-type and supply chain models used in the CBA

6.3.1 Market Pricing

Discussions with stakeholders and assessment of market prices from a range of online sources show that there is the potential for significant variation in prices that can be paid for wet and processed seaweed depending on which market is being targeted. Demand for food products using seaweed is also an aspect which would have to match future farm growth and production. The CBA has therefore been developed to show how a range of different prices and costs impact on the rates of return, payback periods etc. In effect this approach means that the CBA model can be used as a means of understanding how target prices compare to actual proposals and plans, demonstrating the following:

- The viability of different sizes of farm, and yield, when seaweed is sold as a wet or processed product.
- How different types of processing impact on capex and opex, to illustrate the pricing issues or opportunities in terms of being able to develop a viable business model.

6.3.2 The Supply Chain Models

The models considered in the CBA are summarised below:

- Model 1: Seaweed harvested and sold wet to processor, without drying and milling.
- Model 2: Seaweed processed, refrigeration/freezing, cooking, packaging for distribution direct to consumers or retailers.
- Model 3: Seaweed farmed and dewatered for third party drying.

Models 1 and 2 above are self-explanatory. However, model 3 above takes a currently developed supply chain processing opportunity (outwith Scotland) where partly processed seaweed (dewatered, kelp, stored in IBCs) is received by a third party for drying, milling, packaging and sale. This model is considered here for companies/farmers in Scotland and is shown to highlight the other conditions required that facilitate this to become a viable proposition – without the upfront investment in a fully developed processing and distribution facility.

The above models are incorporated within a number of scenarios **for analysis in the CBA**, involving different scales of farming, with 4 metre long-line separation used as the basis of the approach. In addition, the impact of both purchasing and leasing boats for installation, maintenance and harvesting is considered. The scenarios, representing a range of development options, are summarised in **Table 4**.

Table 4. Development-types and baseline scenarios for CBA modelling

Scenario	Cultivation Area	Boat	Distance Between Long Lines	Supply Chain Model ID	Description of any Processing
1	8 ha	Purchased	4m	1	No processing. Seaweed harvested and sold wet to processor, without any drying, milling and packaging
2	32 ha	Purchased	4m		
3	64 ha	Purchased	4m		
4	8 ha	Leased	4m		
5	8 ha	Purchased	4m	2	Seaweed processed – refrigeration/freezing, cooking, packaging for distribution direct to consumers or retailers.
6	8 ha	Purchased	5m		
7	8 ha	Purchased	4m	3	Seaweed processed - dewatered for third party drying, packaging and distribution to the market.
8	64 ha	Purchased	4m		

It should be noted that a number of scenarios in Table 4 describe options which the following CBA section shows have opportunities in terms of being viable business models. Others face challenges in terms of prices that would have to be achieved. The following should also be noted:

- For farms of 8 to 32 ha supply chain partnerships where there is existing processing capacity is required for viable returns on investment
- For larger farmers e.g. circa 64 ha limited investment in limited processing plant can be a part-solution for then accessing the full infrastructure available with third parties – where markets are identified and process are compatible with the operational and capital costs involved.
- For fully integrated supply chain models significantly larger growing areas, with markets identified, are required – this could be taken forward not only by one company, but on a co-operative/collaborative model by a number of seaweed farmers.

7.0 COST BENEFIT ANALYSIS

7.1 Overview

A cost benefit analysis (CBA) model has been prepared from the desk-based reviews, research and stakeholder engagement, for a number of scenarios, involving seaweed farms of different scales and integration, in terms of the supply chain. The costs were discussed with farmers and infrastructure suppliers, and then scaled up for different sizes of farm.

The CBA assigns prices for the outputs from the farms (fresh/wet and processed) and estimates the payback period, internal rates of return etc. Prices have been adjusted for many of the scenarios to provide payback periods less than 10 years, and if possible/realistic, within a three-year period. This approach was used to allow target costs and prices to be considered, to add value to the considerations involved in developing the sector and markets, rather than simply stating that certain types of scale, supply chain model etc are not viable. The steps involved in building the CBA are summarised below:

- Review of data collected and stakeholder engagement results.
- Preparation of development scenarios based on the supply chain members identified/confirmed, and the products/markets associated with these.
- Structuring financial data in a format to indicate the impact of bank lending at different interest rates, the impact of grant support, etc indicating Internal Rates of Return (IRRs) and payback periods.

Sections 7.5 and 7.6 show **potential payback years for different operational models**, for example bulk production (scenario 3) and smaller farm-scale with value addition (scenario 5). Under modest assumptions (validated through consultation) some scenarios are seen to have viable payback periods, though scale, price sensitivity, workboat costs and the cost of seeded line are all strong determinants. Some with the shortest payback period (characterised in Scenario 5) reflect operational models found in other parts of the world, such as the USA and Ireland.

7.2 Growing area and associated data informing the CBA

Table 5. Lengths of longline for different spacings and sizes of farm.

Growing Area (Hectares)	Length of Longline/Seeded Line for Different Separations		
	3m	4m	5m
1	3,333	2,500	2,000
2	6,667	5,000	4,000
4	13,333	10,000	8,000
8	26,667	20,000	16,000
16	53,333	40,000	32,000
32	106,667	80,000	64,000
64	213,333	160,000	128,000
128	426,667	320,000	256,000
256	853,333	640,000	512,000

Table 6. Seaweed yields for different scales of farm and longline spacing

Growing Area (Hectares)	Yield (tonnes) of wet seaweed for different separations (3 to 5m) of Seeded Line		
	3m	4m	5m
1	20	15	12
2	40	30	24
4	80	60	48
8	160	120	96
16	320	240	192
32	640	480	384
64	1,280	960	768
128	2,560	1,920	1,536
256	5,120	3,840	3,072

Table 7. Harvest time data for calculating the number of boat days and manpower costs

Criteria	Metres Separation Distance of Seeded Line		
	3m	4m	5m
Number of lines (approx.) for harvesting / hectare	33	25	20
Total length of line, metres, per hectare	3,333	2,500	2,000
Number of days harvesting per hectare	3.3	2.5	2.0

7.3 Capital costs informing the CBA

The capital costs associating with seaweed farming infrastructure were discussed with stakeholders on the basis of a one-hectare site and the potential, for estimating purposes, of scaling these up for different sizes of farms. These costs have been split into two different categories, as indicated below:

- Class A – costs which have been scaled up pro rata from a 1.0-hectare site.
- Class B- costs which do not increase pro rata with farm size (Table 9).

The costs shown are based on two scenarios – the purchase of a boat, or the hire costs for boats. This is significant because of the feedback from stakeholders indicating how critical this is to provide a viable business model i.e. workboat hire costs have been identified as a barrier.

The capital costs shown in the following tables are applied to the relevant scenarios/development types as described previously in **Table 4**.

Although a range of capital costs for processing plant have been discussed with stakeholders, indicative costs for the purchase of processing plant are included in tables and CBA. These processing costs are based on assumptions/estimates and it is recognised that these may be significantly different to those being considered by companies operating in the sector. The estimates are used to allow prices to be determined that will in turn provide viable returns to be realised. In some cases, however, the prices that are generated using this approach are shown to be significantly higher than the market may pay. This in turn highlights where increased scale and added value needs to be considered, to provide viable business models.

Table 8. Capex - Class A items (increasing pro rata by hectare)

Description	**Capex £ / 1.0 hectare site** *Line Separation Distance in metres*		
	3	**4**	**5**
Estimate of cost of materials per ha (£) including poly/steel rope	10,000	7,500	6,000
Installation cost (£) / ha	5,833	4,375	3,500
Cost of Containers to store seaweed	4,570	3,428	2,742
TOTALS	**20,403**	**15,303**	**12,242**

Table 9. Capex - Class B items (**not** increasing pro rata by hectare)

Size of Harvest Area	Boat Purchase, if applicable	Navigation Aids Costs*	Site Selection	Prospective Leasing/Licence Application	**TOTAL**	
					Boat Hired	Boat Purchased
Up to 32 ha	35,000	3,000	3,000	10,000	**16,000**	**51,000**
32 to 128 ha	70,000	6,000	6,000	20,000	**32,000**	**102,000**
128 to 256 ha	140,000	18,000	12,000	30,000	**60,000**	**200,000**

*Navigation aid costs for increasing scales of farm are not well understood – costs must be considered bearing this in mind (more work required)

Table 10. Capex – costs used in the CBA for farming and processing infrastructure

Descriptions	Capex (£ thousands) for the Scenarios							
	1	2	3	4	5	6	7	8
Class A Items	-122.4	-489.7	-979.4	-122.4	-122.4	-97.9	-122.4	-979.4
Class B Items	-51.0	-51.0	-102.0	-16.0	-51.0	-51.0	-51.0	-102.0
Subtotal	**-173.4**	**-540.7**	**-1,081.4**	**-138.4**	**-173.4**	**-148.9**	**-173.4**	**-1,081.4**
Processing Plant	0.0	0.0	0.0	0.0	-500.0	-500.0	-500.0	-2,000.0
TOTAL	**-173.4**	**-540.7**	**-1,081.4**	**-138.4**	**-673.4**	**-648.9**	**-673.4**	**-3,081.4**

7.4 Operational costs informing the CBA

The operational costs developed for the CBA are based on the growing area and the type of processing, if any, as described previously. The opex is also influenced by whether or not boats are purchased or leased, and the impact of this is described later in terms of viability. The opex is effectively structured into two headings, "expenses" and "cost of goods sold" (COGS). What each of these consists of is summarised below:

- Expenses:
  - Management, Admin, Marketing, Sales Staff
  - Annual Crown Estate Lease Fee
  - Admin Costs
  - Consumables, water
  - Building Rental Cost
  - Building Heat & Power Costs
- COGS:
  - Seeding annual cost
  - Harvesting
  - Maintenance
  - Monitoring
  - Boat hire, if applicable
  - Processing (energy costs, maintenance)

The expenses and COGS referred to above are determined by the size of the farm and how integrated the supply chain model is. The detailed expenses are summarised in Appendix B. The costs focussed on in this report are:

- COGS - Farming, including harvesting.
- COGS - Haulage of wet seaweed to food processor.
- COGS - Preserves (e.g. sauces) - processing and distribution of packaged products (preserved) to food market.
- COGS - Dewatered & third party drying, packaging and distribution.

Table 11. Opex for seeding, per hectare

		Boat Purchased – Cost Per Hectare – *Metres Separation Distance of Seeded Line*			4m separation - % of Cost	Boat Hired – Cost Per Hectare – *Metres Separation Distance of Seeded Line*			4m separation - % of Cost	Comments
		3	4	5		3	4	5		
Seeding Annual Cost	Seeding materials + Seeded String	£8,333	£6,250	£5,000	94%	£8,333	£6,250	£5,000	79%	£2.50/metre, 33 x 100m lines per ha*
	Deployment of String	£560	£420	£336	5%	£560	£420	£336	5%	£140/day x 4 people.
	Deployment boat	£100	£100	£100	1%	£1,200	£1,200	£1,200	15%	£600/day for boat hire, if applicable. Fuel for own boat
	SUBTOTAL PER HECTARE	**£8,993**	**£6,770**	**£5,436**	**86%**	**£10,093**	**£7,870**	**£6,536**	**100%**	

*i.e. 33,000 metres for 10 ha

Table 12. Opex for harvesting, per hectare

		Boat Purchased – *Metres Separation Distance of Seeded Line*			4m separation - % of Cost	Boat Hired – *Metres Separation Distance of Seeded Line*			4m separation - % of Cost	Comments
		3	4	5		3	4	5		
Harvesting	Boat fuel (Est.)	£100	£100	£100	9%					Boat hire includes 2 hands – 4 required.
	Harvesting boat (£/yr)	£100	£100	£100		£4,333	£3,250	£2,600	82%	
	Harvesting labour	£1,213	£980	£840	91%	£933	£700	£560	18%	
	SUBTOTAL PER HECTARE	**£1,313**	**£1,080**	**£940**	**100%**	**£5,267**	**£3,950**	**£3,160**	**100%**	

Table 13. Boat Purchased – operational costs per hectare for maintenance and monitoring

Item	Description	Cost per Hectare Metres Separation of Seeded Line 3	 4	 5	4m separation - % of Cost	Comments
Maintenance Annual Cost	Maintenance (4 FTE days / yr / Ha)	£560	£420	£448	16%	£140/day, 4 people
	Maintenance boat (2 boat days / yr /Ha)	£100	£100	£100	3%	Fuel for own boat
	Materials for repairs (@ £2k/Ha)	£1,000	£1,333	£1,250	46%	
	Diving (2 days inspection / 2 yrs / Ha)	£1,000	£750	£800	26%	£1,000 per day/diver (every 2 years)
Monitoring Annual Cost	Monitoring, tending crops (2 FTE days / month; 8 months)	£187	£187	£187	6%	£140/day labour cost
	Monitoring, tending crops (1 boat day / month; 8 months)	£100	£100	£100	3%	
	SUBTOTAL PER HECTARE	**£2,947**	**£2,890**	**£2,885**	**100%**	

Table 14. Boat Hired – operational costs per hectare for maintenance and monitoring

Item	Description	Cost per Hectare *Metres Separation of Seeded Line* 3	 4	 5	4m separation - % of Cost	Comments
Maintenance Annual Cost	Maintenance (4 FTE days / yr / Ha)	£560	£420	£448	10%	£140/day, 4 people
	Maintenance boat (2 boat days / yr /Ha)	£1,200	£900	£960	21%	£600/day for boat*
	Materials for repairs (@ £2k/Ha)	£1,000	£1,333	£1,250	32%	
	Diving (2 days inspection / 2 yrs / Ha)	£1,000	£750	£800	18%	£1,000/day/diver (every 2 years)
Monitoring Annual Cost	Monitoring, tending crops (2 FTE days / month; 8 months)	£187	£187	£187	4%	£140/day labour cost
	Monitoring, tending crops (1 boat day / month; 8 months)	£640	£600	£480	14%	£600/day for boat*
	SUBTOTAL PER HECTARE	**£4,587**	**£4,190**	**£4,125**	**100%**	

*smaller boat than that required for deployment, as shown in capex costs

Table 15. Summary of operational costs (expenses and COGS) for the different scenarios

	Year One - Opex Details for Each Scenario – 1 to 8							
	1	2	3	4	5	6	7	8
a) EXPENSES								
Management, Admin, Marketing, Sales Staff	-58	-75	-110	-58	-191	-191	-191	-191
Annual Crown Estate Lease Fee Options	-0	-2	-3	-0	-0	-0	-0	
Admin Costs	-4	-6	-11	-4	-4	-4	-4	
Consumables, water	-1	-5	-10	-1	-1	-1	-1	
Building Rental Cost	-12	-24	-24	-12	-24	-24	-24	
Building Heat & Power Costs	-1	0	0	-1	-1	-1	-1	
TOTAL	**-168**	**-477**	**-884**	**-209**	**-1,618**	**-1,349**	**-502**	**-1,774**
b) COST OF GOODS SOLD (COGS)*								
COGS A	-85.9	-343.7	-687.4	-128.1	-85.9	-74.1	-85.9	-85.9
COGS B	-4.3	-17.1	-34.3	-4.3	0.0	0.0	0.0	0.0
COGS C	0.0	0.0	0.0	0.0	-1,283.2	-1,026.5	0.0	0.0
COGS D								
COGS E								
COGS F								
COGS G	0.0	0.0	0.0	0.0	0.0	0.0	-167.3	-1,338.6
Maintenance (% capital equip)	-2.3	-3.8	-3.8	-0.5	-27.3	-27.2	-27.3	-102.3
TOTAL	-92.5	-364.6	-725.4	-132.9	-1,396.4	-1,127.8	-280.5	-1,526.8
TOTAL OPEX	**-168**	**-477**	**-884**	**-209**	**-1,618**	**-1,349**	**-502**	**-1,774**

***Key:**

COGS A - farming, including harvesting
COGS B- haulage of wet seaweed to food processor
COGS C - Preserves (sauces, pestos etc) - processing and distribution of packaged products (preserved) to food market
COGS D - Dried - processing and distribution of packaged products (dried) to food market
COGS E - Dried & Milled - processing and distribution of packaged products (dried & milled) to food market
COGS F- Dried & Milled - processing and distribution of packaged products (dried & milled) to other high value markets
COGS G - Dewatered & Third Party Drying, Packaging and Distribution

7.4 CBA results and pricing

Baseline CBA outputs are provided on the basis of a wide range of prices earned for seaweed, some of which are believed to be beyond the market price at the moment, but which are shown to illustrate what price would need to be commanded for the cost structures used to result in what might be considered as being viable business models. These prices are shown in **Table 16 below** and are further refined in the Sensitivity Analysis undertaken in Section 7.5, where a number of key costs are altered on the basis of the assumptions stated, to show how the prices used can be reduced to provide viable returns on investment.

Table 16. Description of prices used in the baseline CBA

Scenarios Used		Indicative Price, £/Tonne for Baseline CBA	Descriptions
1	Boat Purchase, 4m & 8 ha	£1,750	Wet seaweed sold to processors with high value markets e.g. food, nutraceuticals etc
2	Boat Purchase, 4m and 32 Ha	£1,300	
3	Boat Purchase, 4m and 64 ha	£1,300	
4	Boat Leased, 4m & 8 ha	£1,750	
5	Boat Purchase, 4m & 8 ha Process 1	£16,080	Products processed from frozen and sold to food markets
6	Boat Purchase, 5m & 8ha Process 1	£16,080	
7	Boat Purchase, 4m & 8ha Process 2	£10K-25K	Seaweed dried, milled and sold directly to food, nutraceutical markets on the basis of the following price mix:
8	Boat Purchase, 4m & 64ha Process 2	£10K-25K	20% at £25,000/T 70% at £15,000/T 10% at £10,000/T

Table 17 and Table 18 present the following outcomes for the baseline CBA, for the scenarios previously described:

- Payback periods
- Internal Rates of Return (IRRs) over 3, 5 & 10 years
- Net Present Values (NPVs) using a 3.5% discount rate

The baseline CBA outputs also show the impacts on viability on the basis of the following:

- Reductions in capex of 50%, which could be the result of grant support, for example – to illustrate how this changes the outcomes. This also demonstrates the impact of different capital investment costs more generally on the viability of the model.
- Debt financing of capex by 70%, representing bank loans over 5 years at 5% interest rates (the latter described in 2020 as a reasonable interest rate to assume for new projects, by Scottish Enterprise).
- The CBA outcomes (IRR, payback etc) in the previous section are based on the pricing structure shown in Table 16. The sensitivity analysis after this discusses the impacts of changing these prices.

Table 17. Detailed summary of incomes and costs from the baseline CBA analysis for the different scenarios (shown at Year 5)

CBA Income & Cost Summary	Farming and selling wet seaweed				Farming, processing and selling of seaweed			
	Model 1				Model 2		Model 3	
	1. Boat Purchase, 4m & 8 ha	2. Boat Purchase, 4m and 32 Ha	3. Boat Purchase, 4m and 64 ha	4. Boat Leased, 4m & 8 ha	5. Boat Purchase, 4m & 8 ha Process 1	6. Boat Purchase, 5m & 8ha Process 1	7. Boat Purchase, 4m & 8ha Process 2	8. Boat Purchase, 4m & 64ha Process 2
	Year 5	**Year 5**	**Year 5**	**Year 5**	**Year 5**	**Year 5**	**Year 5**	**Year 5**
Annual Operating Income	210	624	1,248	210	1,833	1,466	315	-1,774
Cumulative Operating Income	1,050	3,120	6,240	1,050	9,166	7,332	1,576	-8,871
Annual Operating Costs	-168	-477	-884	-209	-1,618	-1,349	-502	-1,774
Cumulative Operating Costs	-842	-2,383	-4,419	-1,044	-8,088	-6,746	-2,512	-8,871
Annual Cash flow	42	147	364	1	215	117	-187	748
Cumulative Cash flow	208	737	1,821	6	1,077	587	-936	3,740
Capex	-173	-541	-1,081	-138	-673	-649	-673	-3,081

Table 18. Detailed summaries of scenario viability

Financial Performance	Farming and selling wet seaweed								Farming, processing and selling of seaweed							
	Model 1								Model 2				Model 3			
	1. Boat Purchase, 4m & 8 ha		2. Boat Purchase, 4m and 32 Ha		3. Boat Purchase, 4m and 64 ha		4. Boat Leased, 4m & 8 ha		5. Boat Purchase, 4m & 8 ha Process 1		6. Boat Purchase, 5m & 8ha Process 1		7. Boat Purchase, 4m & 8ha Process 2		8. Boat Purchase, 4m & 64ha Process 2	
	70% Debt	70% Debt + Grant	70% Debt	70% Debt + Grant	70% Debt	70% Debt + Grant	70% Debt	70% Debt + Grant	70% Debt	70% Debt + Grant	70% Debt	70% Debt + Grant	70% Debt	70% Debt + Grant	70% Debt	70% Debt + Grant
NPV, 3 years (000's)	-0	76	64	372	384	861	-118	-57	197	606	-141	145	-1,282	-985	29	1,388
NPV, 5 years (000's)	12	100	116	476	546	1,096	-135	-65	289	768	-129	200	-1,529	-1,187	248	1,812
NPV,10 years (000's)	170	258	677	1,036	1,931	2,481	-131	-60	1,108	1,587	317	647	-2,241	-1,899	3,091	4,656
3 yr IRR	-10%	92%	7%	141%	36%	162%	N/A	N/A	28%	182%	-49%	46%	N/A	N/A	-8%	94%
5 yr IRR	11%	104%	26%	151%	52%	171%	N/A	N/A	46%	190%	-26%	62%	N/A	N/A	12%	106%
10 yr IRR	35%	108%	44%	152%	63%	172%	N/A	N/A	58%	191%	19%	71%	N/A	N/A	36%	110%
Payback Years	**4**	**1**	**3**	**1**	**2**	**1**	**N/A**	**N/A**	**2**	**1**	**7**	**2**	**N/A**	**N/A**	**4**	**1**

7.5 Sensitivity analyses

Sensitivity analysis has been undertaken to demonstrate how the viability changes on the basis of individual changes of the following:

- Seeded line costs reducing to £1.00 per metre (from £2.50 per metre) – by moving to direct seeding methods.
- Yield of seaweed per Kg changing by +2Kg per metre.
- Changing the leasing cost per metre of seeded line
- Reducing prices paid to farmers and/or processors by circa 20%.

The impacts of making these changes is summarised in **Table 19**, for each of the scenarios. For simplicity the results are compared with the baseline CBA outputs in terms of the payback period (years), and on the basis of 70% debt financing being used to pay for the capital costs.

Table 19. Summary of sensitivity analyses results

Parameters Changed	Payback Years for Scenarios (1 to 8) with 70% debt financing							
	1	2	3	4	5	6	7	8
Baseline – for reference	**4**	**3**	**2**	**n/a**	**2**	**7**	**n/a**	**4**
a) Yield of seaweed increased to 8Kg/m from 6Kg/m	1	1	1	1	1	2	n/a	2
b) Crown Estate Scotland leasing cost increased to £0.20/metre from £0.02/metre	5	4	2	n/a	2	7	n/a	5
c) Seeded line @ £1.0/metre	2	1	1	5	2	6	n/a	2
d) Seeded line @ £1.0/metre plus price changes, per tonne:								
£1,500, reduced from 1,750	4	-	-	-	-	-	-	-
£1,000, reduced from 1,300	-	5	-	-	-	-	-	-
£1,000, reduced from 1,300	-	-	3	-	-	-	-	-
£1,500, reduced from 1,750	-	-	-	n/a	-	-	-	-
£8K-£20K, reduced by 20%	-	-	-	-	2	-	-	-
£8K-£20K, reduced by 20%	-	-	-	-	-	6	-	-
£8K-£20K, reduced by 20%	-	-	-	-	-	-	n/a	-
£8K-£20K, reduced by 20%	-	-	-	-	-	-	-	7

Example: Scenario 5, under fairly modest assumptions, could give a payback period of 2 years

7.6 CBA Discussion Points

7.6.1 Overview

The CBA baseline results and sensitivity analyses indicate that there are a number of viable scenarios in terms of achieving a payback of investment for seaweed farms from 8 to 32 hectares, within 3 or 5 years – that is, **if the prices shown for wet and dry seaweed would be acceptable to buyers.**

For illustrative purposes, the difference between scenarios 3 and 5 and the implications, are described now. **Scenario 3** is at the larger end of farm size considered, with **Scenario 5** a small-scale farm. The former involves bulk sales of wet seaweed to a third party which then adds value. **Scenario 5** involves the farmer adding value by using processing infrastructure at the lower cost end of the scale (freezing, cooking, packaging and distribution) i.e. not drying and milling. Products are then sold to retailers or direct to consumers. This scenario reflects the structure of a number of known operational models elsewhere (e.g. in Ireland and the USA). The CBA shows that the price that would have to be paid to a farmer that does not add value to seaweed harvested (Scenarios 1 to 4) may be difficult to realise, unless farming takes place at the larger scale modelled (64 ha).

7.6.2 Detailed Considerations

A number of further points are made below related to the CBA and sensitivity analysis, comparing the debt financing scenarios (70% bank lending for capex) only, for consistency:

- Boat costs – a comparison of Scenario 1 and 4 in the baseline shows that the costs used in the CBA for boat purchasing versus boat leasing have a significant impact on viability – 4 years payback for the former, with no viable return for the latter.
- The extent of the impact of varying yields harvested from a growing area (increased from 6.0 kg/m to 8.0 kg/m) is demonstrated with all except scenario 7 having a very short payback period.
- Increasing the leasing cost charged by Crown Estate Scotland, to £0.20/metre from £0.02 per metre, increases the payback period by circa one year for most of the scenarios shown.
- Reducing seeded line costs from £2.50 to £1.00 per metre reduces the payback period significantly across all of the scenarios (except no. 7) – by 2 years.
- Combining a lower seeded line cost (£1.00/m) with reduced prices, by circa 20%, secures paybacks within 3 to 5 years for most of the scenarios.
- The combination of reduced cost seeded line (£1.00 per metre) with a higher yield (8Kg) and reduced costs is not shown in Table 19, however, this has a significant impact. For example, Scenario 1 has a payback period of 3 years, with a price earned (by the farmer) for wet seaweed of £1,200 per tonne, and viable outcomes for the other scenarios over the time periods modelled, with significantly lower prices – making it potentially more attractive to reach the processors and/or marketplace.
- The impact of increasing the capital costs has also been considered (not shown in the table). For example, increasing the capex in Scenario 5 by 25% increases the payback period from 2 years to 3 years.

The prices that have been identified as being a requirement for viable business models indicate that for smaller farms (e.g. circa 8 hectares) there may be challenges in getting seaweed sold to the market if there is not an added value, processing step involved, e.g. targeting sales to human food markets. For farms of this scale the CBA has indicated that prices of more than £1,000 per tonne would be required would be for payback within a 3-year period. This is a price level which might not be achievable without added value being incorporated in the business model.

8.0 CONCLUSIONS

Seaweed farming is already happening successfully across the world, with increasing levels of interest and developments taking place in the North Atlantic, which is becoming a geographical area of increasing interest for a range of international and national investors, with organisations such as the Bezos Earth Fund and WWF supporting the growth of seaweed farming, a strong driver for this being the environmental benefits that are associated with it, and the potential for carbon savings (e.g. where this substitutes for higher carbon intensity, terrestrially produced materials, foods etc).

The size of farms considered in detail in the cost benefit analysis of this project ranged from 8 to 64 hectares (growing areas) with opportunities identified for returns on investment. Investment in farms will need to be associated with the development of processing infrastructure, to get products to market. A key question is what type of infrastructure, and what are the market drivers associated with this? A challenge with Scotland or rUK markets is the visibility of seaweed as a food item, although this is changing, slowly. Market development efforts will be key to supporting the sector to grow.

The expanding seaweed farming sector in Scotland is shown in this report to have a number of opportunities for growth, with a range of business and supply chain models identified that have the potential to support its future expansion. As well as the challenge associated with markets is the availability of processing infrastructure that can add value and enable higher returns on investment. The more value to be added, then there is the potential for this to involve more capital investment, which in turn requires the feedstock to justify this investment. This is an important aspect of future development, to understand what type of sector the country would be supportive of in terms of its growth i.e. will both large, mega-farms and smaller farms be accepted, or will more, smaller-scale farms be the model that wins out in the future. In the case of there being many small farms established, the Scottish Shellfish Marketing Group has developed model which could be of value to consider, involving a collaborative approach for the development of standards, access to markets (e.g. retailers/supermarkets) and processing infrastructure.

Engagement took place (one to one conversations) with 35 organisations working across the seaweed farming supply chain, to discuss costs, prices, markets, techniques, opportunities and challenges. Collaborative working has been identified as an aspect of supply chain development which is of interest to the farmers and the existing processing infrastructure (developed to date on the basis of wild harvested seaweed). A challenge associated with this will be the different cost structures associated with producing seaweed from farming activities, compared to wild harvesting, the latter having a much lower cost associated with it (at least ten times lower).

Engagement with the fish and mussel farming sectors took place, and there was little opportunity found, in particular with the former, in terms of collaborative working, or for this to be in a position to act as a market e.g. seaweed is not considered to have high enough protein levels to substitute for existing fish-feed products. There may be opportunities for work boats associated with mussel farming to be employed in the installation, support and harvesting of seaweed, however, this has still to be determined. Seaweed farmers were of the view that the types of workboats used by the fish farming sector are too large and expensive, to be deployed for seaweed farming, and in general, the cost of leasing workboats was identified as a significant barrier, which was also shown to be the case in the CBA, where the only options the provided returns on investment involved those where boats were purchased rather than leased. The issue of the latter can also be overcome if significantly lower lease costs can be arranged at a local level.

A further significant cost which has been discussed with stakeholders and modelled is the cost of seeded line. In the baseline CBA model this was included at the rate of £2.50 per metre, which is the current estimate (2021) for providing this. However, other supply options (competition) and advances in the technology mean that this could come down to as low as £1.00 per metre in the near future, a reduction which will significantly improve the viability of many farming operations.

The potential for growing seaweed to act as a mitigation tool, to improve the environments surrounding other aquaculture activities was considered and discussed with stakeholders, however, this approach, known as Integrated Multi-trophic Aquaculture (IMTA), was considered to have the potential for only marginal improvements (e.g. in terms of nitrogen fixing) with negative impacts in terms of the potential applications for seaweed grown for such purposes i.e. it was considered that seaweed farming should be considered as an activity which has the potential to produce high quality products first and foremost, with environmental benefits underpinning this, e.g. in terms of improvements to local ecosystems and, potentially, in terms of carbon.

The growing interest in developing high value markets, will require an increase in either the utilisation of existing processing infrastructure and/or the development of new infrastructure. The latter is particularly the case with respect to innovation, for example, to use seaweed as a new feedstock for new packaging products, and/or increasing quantities of food and other high value products. This infrastructure will need to be developed in Scotland if there is demand and interest in developing added value products, with high levels of innovation e.g. that are associated with new, low carbon products in the future. This type of innovation has the potential to create demand for seaweed farming, and support a healthy, growing sector in the future.

The cost of seaweed farming is significantly higher than wild harvesting. It is therefore the case that if the increasing demand for high value products can be met by increased capture of wild grown seaweed this will prevent the growth of the seaweed farming sector.

9.0 RECOMMENDATIONS

Stakeholder engagement and research has identified a number of opportunities for supporting the growth and sustainable development of a seaweed farming sector in Scotland, as summarised below.

Market development work and collaboration across the supply chain: The example of the Scottish Shellfish Marketing Group may be of value for consideration by the key actors - where co-operative and joint venture partnerships can open doors to the retail sector (e.g. supermarkets), as well as mobilising supply capacity, where standards can be developed, and the barriers associated with investing in costly processing infrastructure can be overcome through pooled investment approaches.

Guidance on how to set up seaweed farms and the licensing process: The development of mapping tools to show where the important fish stock areas are, to avoid conflicts when selecting sites. A big issue is the potential for conflict with the fishing industry.

Licensing timescales: A service which would provide a faster response time than is currently the case would be welcomed, including additional support and hand-holding.

Leasing costs: The current approach to leasing (Crown Estate Scotland), which has been described positively, should continue to be employed in the short-term i.e. with the industry just starting to find its feet leasing cost levels should not be set at levels which are a prohibitive and a barrier to the growth of the sector.

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ENDNOTES

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