Understanding the potential scale for seaweed-based industries in Scotland

Final report

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For:

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Executive Summary

Overview

There is growing interest in further developing the existing commercial seaweed-based industry in Scotland. The current industry is relatively small-scale with many businesses being considered artisanal (micro-enterprises), although a few larger companies are well established. There is also a wide range of organisations involved in supporting and developing the seaweed-industry in Scotland through research and development (R&D), innovation and enterprise.

In 2020, the sector was almost entirely dependent on wild harvesting of seaweed for use as raw material, primarily the species *Ascophyllum nodosum* (Egg wrack), although a wide range of other species are also harvested in lower quantities. Whilst interest in cultivating seaweed and incorporating farmed seaweed into products is high, commercial farming in Scotland is still in its infancy (one commercial farm and two research farms in 2020), although the number of marine licence applications, and licensed sites, for cultivating activities is increasing. Consultation with stakeholders[1] highlighted a range of barriers to the development of seaweed cultivation in Scotland, including:

- Large start-up investment costs, access to finance and financial risk
- The relatively low value and uncertainty regarding markets for species that can currently be cultivated
- The scale of cultivation potentially required to achieve economic viability (and need for mechanisation to achieve these scales)

[1] Stakeholders consulted for this study included seaweed-based industry stakeholders (e.g. existing businesses, potential new entrants, industry representatives) and wider stakeholders comprising regulators, other aquaculture consenting bodies and local enterprise, innovation and research organisations or institutions.

- The need for supply chain and infrastructure development within Scotland

In 2020 the Scottish seaweed-based industry as a whole had an estimated Gross Value Added (GVA) of £510,000 per annum and employed a total of 59 people[2]. Seaweed-based products ranged from relatively low value processed seaweed for inclusion in animal feed, to higher value products such as food for direct human consumption, horticultural products and bioactive products for use in the cosmetic, nutraceutical and pharmaceutical industries.

There was the intention for growth amongst almost all businesses consulted, both in terms of increasing production for existing markets and developing new products for existing and new markets. There was also interest in the development of biotechnology processes enabling the production of multiple high value products. This report presents two potential future scenarios exploring how the future development of the industry could impact on Scotland's economy and communities.

Global markets and status of Scottish Industry

The global seaweed industry is estimated to be worth €8.1 billion per year (Barbier et al. 2019). Globally, seaweed production is dominated by cultivated seaweed from Asia, whilst in Europe, production is predominately from harvesting wild seaweed. Whilst there is increasing focus on cultivating seaweed in Europe, the sector is still an emergent industry and relatively small-scale. Wild seaweed harvesting in Scotland is of the order of 8-15 thousand tonnes per year[3], which is less than the production from wild

[2] Based on the reported and estimated data for eight seaweed-based companies, whose core business relates to seaweed, for which data was available.

[3] This is likely to be an underestimate for a number of reasons including that harvested volumes from privately owned (as opposed to Crown Estate Scotland owned) land are not included (see Section 4.2 in the main report for further detail). In 2020, a maximum of approximately 15,000 tonnes of seaweed (all species combined) was consented for harvesting on Crown Estate Scotland owned land/seabed, although it was not considered that harvesting was undertaken at the maximum capacity consented.

harvesting in other European countries such as Norway (141-169 thousand tonnes per year), France (19-69 thousand tonnes per year) or Ireland (around 30 thousand tonnes per year).

Seaweeds can be used as raw material for multiple end uses (human foods, hydrocolloids, animal feed, horticultural products and bioactives for use in nutraceutical, pharmaceutical and cosmeceutical industries). Wider applications include potential for bioremediation purposes. There is growing demand in EU markets for seaweed-based food products (7-10% per annum) and the bioactive supplement market (6-7% per annum up to 2025). No information on future market trends for seaweed-based animal feed or horticultural products was sourced, however some stakeholders thought these could both be high growth markets. Similar to several other countries (e.g. Norway, France, Ireland), there is interest in Scotland for using biotechnology to develop a circular (zero waste) economy using cultivated seaweed to produce multiple products with a range of values.

Scottish seaweed-based products face competition from other countries for all product markets (e.g. France and Spain for sea vegetables; France and Portugal in the bioactives sector), however some Scottish products have already penetrated global markets and the Scottish sector could potentially benefit from promotion of Scottish seaweed provenance due to the high profile of Scottish food and drink globally.

Scenario analysis

Two projected future growth scenarios were developed to explore the potential impacts of seaweed-based industries on the Scottish economy, communities and wider industries to 2040. The growth scenarios were developed for key existing product types and those most likely to develop, informed by the review of the current seaweed industry in Scotland, stakeholder consultation on aspirations for growth, raw material requirements, processing capability, constraints to sector growth and evidence of trends in market demand. Both scenarios assume that all projected sector growth including the establishment of new seaweed-related businesses occurs within Scotland.

The scenarios were:

- **Business as Usual (BAU)**: the sector continues to grow through increased production of existing products and development of new high value products. Commercial-scale seaweed farming does not develop, and raw material is supplied entirely by wild harvesting; and
- **Higher Growth**: Commercial-scale seaweed cultivation develops, providing additional raw material and enabling a higher growth of the component industry sectors. A biorefinery is developed in Scotland utilising cultivated seaweed.

Under the **Business as Usual (BAU)** scenario, it is assumed that:

- The food product sector grows 5% per year, with one new business established each year to 2030, then one every other year to 2040.
- The bioactives product sector has 7% growth per year, with two new businesses established (in 2025 and 2030);
- There is no substantial growth in the animal feed sector (growth rates confidential);
- The horticulture product sector experiences high growth to 2025, then lower growth rates to 2040 (rates confidential).
- Raw material for this growth is supplied entirely by wild harvesting of seaweed in Scotland, with supply increasing to 25,000 tonnes by 2040**.**

This scenario is projected to generate a total turnover of £22.1 million per year by 2040, comprising £15.4 million for businesses who produce seaweed-based products and £3.3 million for their supply chain, as well as £2.9 million for seaweed production and £500,000 for their supply chain. This contributes £11.5 million in GVA per year to the economy by 2040 and a further £1.9 million once induced impacts are included[4].

[4] Induced effects take account of spend by the people employed directly and indirectly on local goods and services. This then provides an additional benefit to the local economy.

This activity is estimated to support 130 FTE jobs by 2040 and a further 30 FTE in the wider economy once induced impacts are included.

Under the **Higher Growth** scenario, it is assumed that:

- The food sector grows 10% per year, with one new business established each year to 2030, then one every other year to 2040;
- The bioactives sector grows 10% per year, with three new business established (in 2025, 2030 and 2035);
- There is no substantial growth in the animal feed sector (growth rates confidential);
- In the horticulture sector one new business is established every 5 years (growth rates confidential);
- The biotechnology sector develops, with one biorefinery business operational by 2025 (growth rates confidential).
- Raw material required for this growth is 54,000 tonnes by 2040, with 30,000 tonnes from wild harvesting and 24,000 tonnes from cultivation.

This scenario is projected to generate a total turnover of £71.2 million per year by 2040, comprising £52.6 million for businesses who produce seaweed-based products and £10.5 million for their supply chain, as well as £3.5 million for seaweed production (wild harvesting) and £590,000 for their supply chain, and £2.8 million for businesses who are cultivating seaweed and £1.2 million for their supply chain. This contributes £38.5 million per year in GVA to the economy by 2040 and a further £6.6 million per year in GVA once induced impacts are included (to reflect additional spend by those employed directly and indirectly). Overall, this would mean total GVA of £45.1 million by 2040, which could represent 0.025% of Scotland's overall GVA by 2040. This activity is estimated to support 400 FTE jobs by 2040 and a further 90 FTE in the wider economy once induced impacts are included.

Wider socio-economic impacts at the national level are unlikely to be highly noticeable by the majority of the community but may be more noticeable at regional level and could be significant should activity be located in smaller rural communities. The wider

socio-economic impacts were explored in an illustrative island and mainland community.

- **Under the BAU scenario**, if 25% of the total industry growth was concentrated in an island community, GVA was estimated to increase by 0.5% and unemployment decrease by 12% by 2040. In a mainland community, GVA was estimated to increase by 0.2% and unemployment decrease by 3% by 2040.
- **Under the Higher growth scenario**, if 25% of the total industry growth was concentrated in the island community, GVA was estimated to increase by 1.6% and unemployment decrease by 36% by 2040. In the mainland community, GVA was estimated to increase by 0.7% and unemployment decrease by 8% by 2040.

Increased economic prosperity is likely to have positive impacts on job opportunities, disposable income and the costs of living. Increased employment will increase household net income. There will be positive knock-on effects for local businesses in the community. In particular, potential positive impacts are expected on the long-term sustainability of supply chains. There is potential for some temporary disruption if migration is required to fill some skilled jobs, potentially felt by the local population in addition to increased demand on essential services (e.g. schools, housing). This is more likely to occur within more remote communities with small populations.

Careful planning and location of seaweed industry could thus incentivise local and regional economies, whilst making a substantial impact on the wellbeing of individuals, communities and wider industry at a local level. Development of seaweed cultivation will increase competition for ‘sea area’ and interaction with other marine sectors and will need to be managed.

Conclusions

The current seaweed sector in Scotland has an estimated total turnover of around £4 million per year, and total GVA estimated at £510,000 per year. Although its scale and economic impact is small relative to other industry sectors (e.g. fishing), it provides important jobs and income locally, particularly in island communities. The sector is currently almost entirely based on harvesting of wild seaweed and dominated by small- and micro-scale enterprises.

There is growth potential in the seaweed industry; raw material requirements for this growth will continue to be met in the immediate future through wild harvesting although there is strong interest from stakeholders to develop seaweed cultivation to supply existing and emerging markets for a variety of seaweed products. Key constraints for seaweed cultivation relate to economic feasibility of farming compared to the cost of wild harvesting, including large start-up costs and access to investment and funding to establish farms and the limited range and value of species that can currently be cultivated. Review of the consenting process for wild harvesting seaweed and cultivating seaweed was outwith the scope of this study. However, several industry and wider stakeholders highlighted that the future of the seaweed-based sector depended upon the proportionate regulation of access to the wild seaweed resource and timely determinations on consent to wild harvest to enable planning of capital investment and research into product development. Similarly, the time taken to receive a marine licence for seaweed cultivation was raised as a potential issue for the industry.

The scenarios explored for growth of the sector indicate that impacts are likely to be positive with increased economic prosperity likely to have positive impacts on job opportunities, disposable income and costs of living, as well as on the long-term sustainability of supply chains. However, temporary disruption is possible if migration is required to fill some skilled jobs. Careful planning and location of the seaweed industry could incentivise and help diversify local and regional economies.

Achieving the level of growth foreseen in the Higher Growth scenario would require investment and funding support, and potential interactions with other marine industries (e.g. fishing) to be carefully managed and minimised.

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1 Introduction

1.1 Background

1.1.1 Seaweed (marine macroalgae) provides a source of food, animal feed and fertiliser as well as being used in a wide range of industries such as cosmetics, nutraceuticals and pharmaceuticals. The global seaweed industry has been estimated to be worth €8.1 billion per year (Barbier et al. 2019). At a global level, the production of seaweed as a raw material is dominated by cultivated seaweed from Asia, whilst in Europe, production is predominately via harvesting of the wild resource.

1.1.2 Scotland's nearshore waters host a wide range of different seaweed species with a high abundance of some potentially commercially important species (Burrows et al, 2018). Although the established seaweed-based industry in Scotland is small, there is a growing interest in further developing the commercial seaweed-based industry, for example through creating new high value products from seaweed, new entrants to the sector and through cultivating seaweed to supply various existing and emerging markets (e.g. Stanley et al., 2019).

1.1.3 The Scottish Government has initiated a Seaweed Review, overseen by a Seaweed Review Steering Group, to help ensure existing seaweed harvesting activity and future proposals are sustainable, and that Scotland's marine environment is protected. As part of this wider review, the Scottish Government is in the process of building its evidence base to understand how local seaweed-based industries may develop based on resources (harvest from the wild, cultivated or imported from other countries) that could be available to businesses that locate in Scotland. The potential socio-economic impacts of this are also being explored.

1.1.4 ABPmer and RPA were commissioned by Marine Scotland and Crown Estate Scotland to consider the current status and future growth opportunities for Scottish seaweed-based industries, develop plausible scenarios for the industry development in Scotland and assess the potential impacts (positive and

negative) on the economy and wider society. This research will inform the Scottish Government Seaweed Review's wider research needs on the environmental and socio-economic implications of a growing seaweed harvesting and cultivation sector.

1.2 Study aims and objectives

1.2.1 The research focuses on understanding the potential scale and type of seaweed-based industries that currently exist, or may establish, in Scotland based on potential sources of raw material (seaweed) and emerging market opportunities for various seaweed-based products. This includes understanding the wild or cultivated seaweed resource that would need to be made available to industries establishing in Scotland, the potential sources and volumes of the raw material required, market opportunities and potential, and their probable impacts on the economy and wider society in Scotland. The overall aim of the research is to increase understanding of the potential for seaweed-based industries in Scotland.

1.2.2 The specific objectives of the research are to:

- Determine the potential scope (e.g. by product type or species), scale (volumes, turnover, gross value added (GVA) and employment) and location of seaweed based industries that may establish in Scotland, clearly setting out where there is potential to rely on wild growing seaweed species, cultivated species or imported raw material .
- Identify how the supply chain for various seaweed industries that may establish in Scotland may develop including an assessment of the potential size of their associated indirect economic impacts (turnover, GVA and employment) – upstream and where appropriate downstream.
- Exploring the wider socioeconomic consequences on other industries and communities across Scotland that may arise from both the direct and indirect impacts from local seaweed-based industries, identifying the other industries and communities in Scotland that may be affected positively or negatively by development of seaweed industries and the nature of impacts on these communities.

1.2.3 These objectives were addressed by developing projected future growth scenarios up to 2040. It should be noted that the projected future scenarios have been developed within the context of the current regulatory regime for wild harvesting and seaweed cultivation (described in Appendix A). It was not within the scope of the current study to consider the potential implications of climate change within the projected scenarios. Furthermore, whilst the impact of the UK's recent exit from the European Union and of the COVID-19 pandemic were not specifically accounted for within the projected scenarios, it is acknowledged that these two recent events likely increase the uncertainty around future market opportunities.

1.2.4 The methodological approach to addressing these objectives is described in the relevant report sections below with further detail provided in appendices.

2 Overview of seaweed products and uses

2.1.1 Seaweeds can be used as a raw material for multiple end uses including human foods, animal feed, horticulture and fertiliser, hydrocolloids, bio-actives used in the nutraceuticals, pharmaceuticals and cosmeceuticals industries, and biofuels (Cefas, 2016; Stanley et al., 2019).

2.1.2 The categories of seaweed-based products used within this report to compare the industry in other countries with Scotland and for the economic analysis are summarised in Table 1 (with further description provided in Appendix B). It should be noted that some of these categories overlap by virtue of their eventual end uses. For example, hydrocolloids are used in both human food products and pharmaceuticals and other personal care products. Equally, nutraceuticals might be considered as human food as products are ingested as a dietary supplement, although for the purposes of this study, they have been considered within the bioactive category.

2.1.3 It should also be noted that there are other novel and innovative applications for seaweed that have not yet been taken up on a large scale and remain in development. This includes using seaweed as a feedstock for biotechnology processes, such as biorefining[5] to extract a range of products (with a range of values) from the whole seaweed plant, and/or the production of novel biomaterials to create alternative packaging materials. These biotechnologies remain in development in Scotland and they have been considered further within the projected future scenarios within Scotland (see Section 6).

2.1.4 Conversely, although there has been considerable interest over the last decade in the use of seaweed (particularly kelps) as a feedstock to produce biofuels, seaweed-based biofuels still face issues such as scalability and economic viability, whilst competitiveness and performance against other feed stocks

[5] A biofinery approach to seaweed production has been described by Cefas (2016), Stanley et al. (2019) and BIM (2020) and is described further in Appendix B.

need to be considered (Bruton et al., 2009; SARF, 2016; Stanley et al., 2019). As such, biofuels are considered unlikely to contribute commercially to the seaweed-based industry in Scotland over the next 20 years and are not considered further within this study. In general, opinion obtained from a range of industry and wider stakeholders (e.g. researchers) consulted to inform this work agreed with this decision.

2.1.5 Alongside extractive seaweed industries and products, seaweeds have wider potential applications, for example carbon storage ('blue carbon') and bioremediation purposes[6]. However, due to the emerging nature of these industries and the difficulty of evaluating such ecosystem services, such wider applications have not been considered further within the socioeconomic analysis.

[6] As efficient absorbers of nutrients and contaminants, seaweeds have the potential to be used to improve water quality, for example, assimilating waste released from finfish aquaculture installations in a process referred to as integrated multi-trophic aquaculture (IMTA; Cefas, 2016).

Table 1. Product categories for seaweed uses

Product category	Description	Scoped into the socioeconomic evaluation
Human food	Seaweed products that are intended for human consumption	Yes
Animal feed	Seaweed products that are incorporated into animal feed	Yes
Horticulture	Seaweed products to aid plant cultivation such as fertiliser and soil conditioners	Yes
Bio-actives (cosmetics, pharmaceuticals, and nutraceuticals)	Seaweed products for use in personal care and health applications (cosmetics, pharmaceuticals, and nutraceuticals)	Yes
Hydrocolloids	Seaweed extracts such as alginates, agar, carrageenan	Yes
Biotechnology	Using seaweed as a raw material for biotechnology processes that extract a range of high value products or novel products	Yes
Biofuels	The use of seaweed to produce energy and fuels	No
Bioremediation	The use of seaweed to remove nutrients and contaminants from water to improve water quality	No

3 Status of the seaweed-based industry in countries comparable to Scotland

3.1.1 A review of the scale and value of the seaweed-based industry sectors in countries considered comparable to Scotland (on the basis of their utilisation of the same or similar seaweed species for commercial purposes) was undertaken via a desk-based review, supplemented by consultation with relevant industry experts[7], from Scotland and other countries where possible. The purpose of the review was to inform the development of projected future scenarios for the Scottish seaweed-based industry (Section 6), with regard to the supply of raw seaweed material and competition for products and markets.

3.1.2 The case study countries reviewed were Chile, Norway, France, Ireland and Iceland. The general development of the seaweed-based sector in these countries, including the main species harvested and/or cultivated, tonnages, the main products and markets and industry structure (where information was available) are described in detail in Appendix C. A brief summary of the key points is provided below and in Table 2 and Table 3.

3.1.3 In contrast to Asia and Africa, where raw seaweed material is predominately cultivated, in Europe and Chile, seaweed is almost entirely harvested from the wild.

3.1.4 Kelp species dominate production from wild harvesting in Chile, Norway and France where they are mainly used to produce alginates. On a global scale, approximately 40,000 tonnes of alginate is produced annually, the vast majority

[7] Such contacts were determined through the desk-based review above and liaison with the Project Steering Group (PSG) and the Scottish Seaweed Industry Association (SSIA)

of which is high M alginate[8] (properties low gel strength, elastic gel) which Chinese companies can supply at very low costs compared to the European producers (information from stakeholder input). The remaining alginate produced is high G alginate (properties high gel strength, brittle gel). Norway hosts the largest alginate extraction facility in Europe (Dupont) and produces around two thirds of total European production and almost all of the global supply of high G alginate. The global size and value of the hydrocolloid market in 2016 (excluding China) was estimated at €488 million for agar (55,000 tonnes), €258 million for carrageenan (13,000 tonnes) and €237 million for alginate (16,000 tonnes) (CBI, 2018).

3.1.5 The use of seaweeds as food products is established in Chile and France and is likely to increase. This is due to growing interest in the sea vegetable market in western countries in Europe. In 2013, the wholesale value for sea vegetables was estimated to be €24 million (Organic Monitor, 2014). The use of seaweeds in bio-active products (cosmetics, nutraceuticals, and pharmaceuticals) is also expected to grow.

3.1.6 In contrast to Chile, which farms relatively large volumes of red seaweed (*Gracilaria*) for agar production, seaweed cultivation in Europe is still an emergent industry and small-scale, although in Norway the number of licences granted for the cultivation of seaweeds, companies involved and tonnages harvested from farmed sites have all gradually increased since 2015 (BIM, 2020). Species cultivated in European countries mainly include *S. latissima, A. esculenta,* and *U. pinnatifida* for use in human food and animal feed.

3.1.7 The implications of the scope and scale of the seaweed-based industry in these countries in relation to the development of the Scottish industry is considered further within Section 6 (Projected future growth scenarios).

[8] The physical properties of alginate, which influences its application within the food and chemical industries, vary depending on its uronic acid composition (the ratio of mannuronic acid to guluronic acid; the M/G ratio).

Table 2. Summary of wild harvesting seaweed industry in countries comparable to Scotland

Country	Wild harvest volumes (t)*	Species	Method	Products and trends
Chile	330,000 to 518,000	Numerous kelp and red seaweeds	Hand	Relatively stable production levels with some fluctuations. Main goods of value are hydrocolloids.
Norway	141,000 to 169,000	Mainly *Laminaria hyperborea* (Cuvie); *Laminaria digitata* (Oarweed)	Mechanical (rake type dredge)	Stable levels of wild harvesting production. Has the largest alginate extraction facility (DuPont), supplying most of European demand. Seaweed imports sometimes relied upon to supply demand in processing.
France	19,000 to 70,000	*Laminaria digitata* (Oarweed) (highest volumes) *Laminaria hyperborea* (Cuvie) Some edible seaweeds	Mechanical (rake type dredge) Hand	Wild harvesting production has fluctuated over recent years. Chemical and food-processing (hydrocolloids) are the main markets for seaweed (seaweed imports sometimes relied upon to supply demand in processing), as well as animal feed, fertiliser and health care products (e.g. cosmetics and pharmaceuticals). Human food is also an important market for edible seaweeds and demand is increasing in Europe.

Country	Wild harvest volumes (t)*	Species	Method	Products and trends
Ireland	30,000 (estimated)	Ascophyllum nodosum (egg wrack) *Laminaria hyperborea* (Cuvie) Some edible seaweeds	Hand Mechanical	Stable levels of wild harvesting production, which is used as animal feed and fertiliser. Both mechanical wild harvesting and cultivation is expected to increase to take advantage of markets in bioactives and food.
Iceland	17,000 to 21,000	*Ascophyllum nodosum* (egg wrack) *Laminaria digitata* (Oarweed) *Laminaria hyperborea* (Cuvie)	Mechanical (rake type dredge) Mechanical (modified vessel)	Stable levels of wild harvesting production with exports of dried and ground seaweed meal.
* The range of volumes provided are rounded tonnages between 2009 and 2017 according to FAO (2019).				

Table 3. Summary of cultivated seaweed industry in countries comparable to Scotland

Country	Cultivated volumes (t) *	Species	Trends
Chile	12,000 to 17,000	*Gracilaria* sp.	Stable levels of cultivated production since 2013. Dominated by one species (*Gracilaria*) for agar production.
Norway	169	*Saccharina latissima* (Sugar kelp) (165 t) *Alaria esculenta* (Dabberlocks) (2 t)	Emerging cultivated production for use as high value food ingredients and exploring new opportunities in bioenergy, pharmaceuticals and animal nutrition. Research programme focussed on characterisation of the seaweed biomass (e.g. chemical composition) and the development of technology for biorefinery processes and establishment of high-value and bulk product pipelines (BIM, 2020).
France	Discrepancies in reported volumes: < 100 to 380** (Cefas, 2016) 50 tonnes (BIM, 2020) 500 tonnes (FAO statistics cited in BIM, 2020)	*Undaria pinnatifida* (Wakame) *Saccharina latissima* (Sugar kelp)	Substantial investment in research to develop cultivation of key seaweed species (BIM, 2020)

Country	Cultivated volumes (t) *	Species	Trends
Ireland	40	Red and brown seaweeds	Small-scale cultivated production, modest increases between 2011 and 2013.
Iceland	No cultivated production	No cultivated production	No cultivated production.

* The range of volumes provided are rounded tonnages between 2013 and 2017 for Chile (FAO, 2019); 2018 for Norway (BIM, 2020); 2009 to 2013 (Cefas, 2016) and 2018 (BIM, 2020) for France; and 2018 for Ireland (BIM, 2020).

** This volume estimate includes unidentified miscellaneous aquatic plants not included under brown, red or green seaweeds in Cefas (2016) and hence assumed not to refer to the production of seaweed (macroalgae).

4 Status of the current seaweed-based industry in Scotland

4.1 Approach

4.1.1 This section provides a review of the current (baseline) Scottish seaweed-based industry with regard to the:

- Types of businesses involved and operational structure;
- Seaweed species utilised and the source of the raw material;
- Range of processing undertaken;
- Products produced;
- Industry's locational distribution; and
- Estimated socio-economic value (turnover, GVA and employment) of the sector per product group.

4.1.2 The baseline presented is based on a desk-based review of publicly available data and information provided through consultation. Stakeholders consulted for this study included industry stakeholders (i.e. existing seaweed-based businesses, potential new industry entrants and industry representatives) and wider stakeholders comprising regulators, other aquaculture consenting bodies and other institutions/organisations involved in enterprise, innovation and/or research.

4.1.3 For the purposes of this study, the baseline evaluation of the current seaweed-based industry has considered companies, community groups or other types of organisation whose core business[9] relates to seaweed with regard to the

[9] A company or organisation's core business was considered to relate to seaweed if over 50% of their business or products related to seaweed/seaweed products (confirmed through consultation or judged from publicly available information).

harvesting, cultivation, processing and/or production of goods containing seaweed[10] within Scotland. Other actors within the seaweed-related industry, (e.g. upstream supply chain companies providing equipment or institutions/organisations involved in enterprise and R&D), are also described but are not considered quantitatively in the baseline economic analysis.

4.1.4 Seaweed-related businesses identified through searches and liaison with the Project Steering Group (PSG) were contacted via email and invited to engage with the study via a telephone interview[11]. During the interviews information on the following was sought (see Appendix D for the full questionnaire):

- Type of products and proportion of business that relates to seaweed;
- Location of business;
- Location of markets;
- Type, source and volumes of raw material used;
- Processing of raw material and supply chain requirements;
- Current volume and value of activity (turnover);
- Operational and capital costs;
- Employment (number of FTE, skills shortage, location of the workforce);
- Constraints to current business;
- Future vision for the company, including identification of opportunities/new markets and any potential constraints, and vision for the sector as a whole in Scotland.

4.1.5 Semi-structured telephone interviews were also held with wider stakeholders, to further inform the analysis of the current status of the industry, future products, emerging market opportunities and growth potential

[10] Where products containing seaweed comprise the majority of the products produced or sold.

[11] Note, three businesses identified at a relatively late stage in the project were not contacted directly. Hence information on those businesses was obtained through publicly available information.

4.1.6 A total of 22 interviews were conducted comprising seaweed-related businesses/organisations (n=12) and wider stakeholders (n=10). For confidentiality reasons these stakeholders are not listed in the report. Further detail regarding the methodological approach to the baseline review is presented in Appendix E.

Limitations

4.1.7 The review identified 20 companies/organisations in Scotland whose core business relates to seaweed, of which 12 engaged in the consultation. Whilst to the best of our knowledge the data presented captures most key seaweed-related businesses in Scotland, obtaining an exhaustive list of seaweed-related businesses in Scotland, for example from a regulatory body or an industry association, was not possible. As such, it is acknowledged that the data presented is likely to underestimate the scale of the sector.

4.1.8 Furthermore, it is important to note that the stakeholder consultation was conducted in early 2020 and hence the baseline presented may underestimate the level and value of the sector activity in 2021.

4.2 Overview of the current seaweed-based industry in Scotland

Businesses and supply chains – wild seaweed harvesting

4.2.1 The vast majority of the current sector in Scotland utilises wild harvested seaweed sourced from Scottish waters, rather than cultivated seaweed. Of the nine seaweed-related businesses involved in harvesting and/or processing of wild seaweeds in Scotland (for which information was sourced), seven are

classed as micro-entities and two are classed as small companies as per Companies House (2019) definitions[12].

4.2.2 The majority of micro-entities operate at a small-scale, harvesting wild seaweed by hand. Most of these businesses can be considered as artisanal operations, harvesting small amounts (up to a tonne of seaweed per annum) where the production process (harvesting, processing, production, and packaging) is done entirely in-house. In general, equipment requirements are low-tech (e.g. air-drying racks, drying ovens, mills, sieves and packaging material). Packaging, labelling and delivery logistics are also requirements. A generic schematic representation of the production and supply chain for these types of businesses is shown is Figure 1.

4.2.3 Some of the micro-entities harvest or process slightly larger quantities of seaweed (up to 50 tonnes per annum) and also employ the use of external businesses in the manufacture and packaging of their products (Figure 2). One company has more than one seaweed supplier, including one outwith Scotland, to ensure a reliable (constant) supply of seaweed (i.e. to de-risk the supply chain which in general is considered under-developed due to lack of investment in Scotland; see also Table 8, Section 5).

[12] **Micro-entities** are those that meet at least two of: annual turnover of not more than £632,000; balance sheet total of not more than £316,000; and average number of employees must not be more than 10. **Small companies** must meet at least two of: annual turnover of not more than £10.2 million; balance sheet total of not more than £5.1 million; and average number of employees must not be more than 50. **Medium-sized companies** must meet at least two of: annual turnover of no more than £36 million; balance sheet total of not more than £18 million; and average number of employees must not be more than 250. Any companies that do not meet the criteria for micro-entities, small or medium are **large companies**.

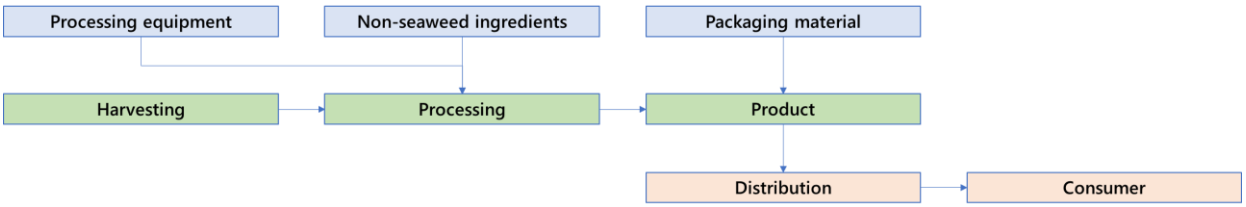

Figure 1. Generic supply chain model for micro-sized seaweed harvesting businesses in Scotland with in-house production – green = internal operations, blue = upstream supply chain (mostly outwith Scotland), red = downstream supply chain

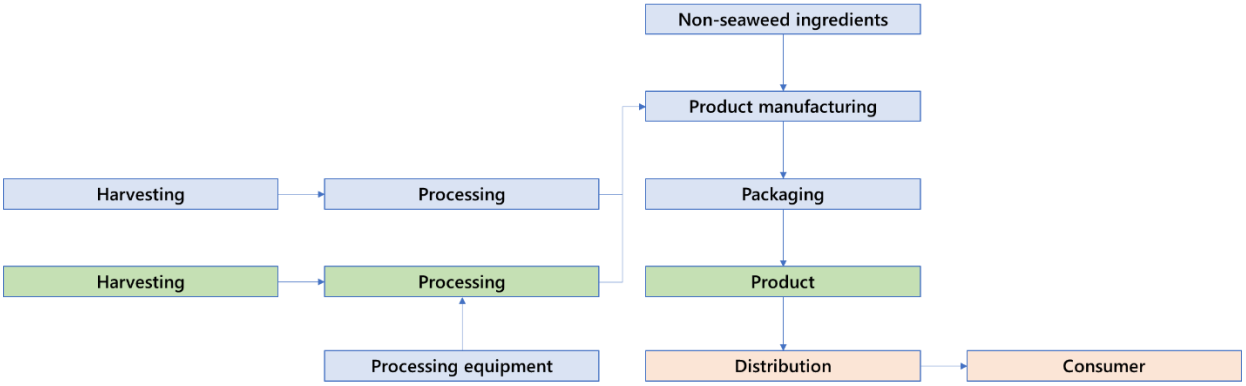

Figure 2. Generic supply chain model for micro-sized seaweed harvesting businesses in Scotland that outsource production – green = internal operations, blue = upstream supply chain (mostly outwith Scotland), red = downstream supply chain

4.2.4 The companies defined as small by Companies House definitions, operate at a relatively large scale compared with the micro-entities, whereby seaweed is harvested mechanically (using a specially modified vessel with cutter) and/or by hand (sometimes with the use of a rake and vessel). These businesses harvest larger volumes of seaweed (over a thousand tonnes per annum) which are processed by drying and milling to individual end-user specifications which can be used directly or are subsequently sold to supply other companies that make seaweed-based products (depending on the application). A generic schematic representation of the production and supply chain for these types of businesses is shown in Figure 3.

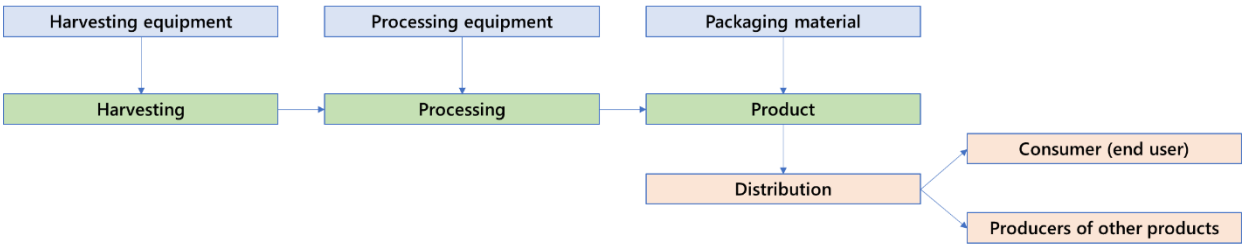

Figure 3. Generic supply chain model for small-sized seaweed harvesting businesses in Scotland – green = internal operations, blue = up-stream supply chain (mostly outwith Scotland), red = downstream supply chain

Species, products and markets – wild harvested seaweed

4.2.5 The range of seaweed species that are currently wild harvested in Scotland and the product categories that they are used in are shown in Table 4. The table also shows the maximum consented harvest tonnages under CES licence[13] for each species.

4.2.6 The species harvested in the greatest quantity in Scotland is *A. nodosum* (egg wrack), which is harvested both by hand and mechanically from the intertidal area. *A. nodosum* is processed for direct use as animal feed and soil conditioners, as well as being used to produce liquid seaweed fertiliser extracts. It is also processed to customer specifications to supply other companies for the production of human food products, and bioactives within the nutraceuticals and cosmetics industries.

4.2.7 Many of the micro-entities in Scotland tend to hand harvest a diverse range of intertidal seaweed species, including kelps, wracks, red and green seaweeds. Of these species the kelps *Laminaria digitata* (oarweed), *Saccharina latissima*

[13] Harvesting seaweed from the foreshore or seabed (i.e. below mean low water springs) managed by Crown Estate Scotland (CES), for commercial reward, requires a licence to be obtained from CES. Where the foreshore is owned by a landowner other than the Crown, the landowner's permission is required

(sugar kelp) and the red seaweed *Palmaria palmata* (dulse) comprise the largest proportion of the total harvest. The uses and products produced in Scotland from these species include human foods and cosmetic products containing seaweed material. Aside from where seaweed is harvested and sold fresh (in one instance), these types of products are considered higher value 'speciality' seaweed products (see Figure 14 in Cefas, 2016).

4.2.8 The majority of seaweed-related businesses identified in this study sell their products mainly to retailers, and direct to consumers (e.g. cafes, restaurants, markets, or via online or shop sales). These are primarily within the locale of the business in Scotland, or otherwise within the UK. A few of the larger businesses also sell products to processors and wholesalers, sometimes via distributors, in the UK as well as internationally such as in Europe, the Middle East, and United States of America (USA).

4.2.9 Whilst Table 4 indicates the maximum consented tonnage of each species that can be harvested under CES licence (approximately 13,000 tonnes in total across all licences), this does not necessarily represent actual harvested volumes and does not account for species harvested on private land not owned by CES[14], or species harvested at smaller scales (see Table 4 footnote).

[14] The seaweed 'activity mapping' exercise undertaken by the Seaweed Review Group in 2019 indicated that, at that time, there were 13 locations in Scotland in which wild seaweed harvesting was undertaken for commercial purposes. At nine of these locations landownership falls in some areas to the CES and in others to private landlords. A further four areas are solely under private landownership. The volume of seaweed harvested from privately owned land is not reported and hence not known. It is assumed that the volumes harvested from privately owned land is only likely to be substantial (e.g. volumes > 1,000 wet weight tonnes p.a.) for the three larger-scale wild seaweed harvesters in Scotland. Of these seaweed harvesters/companies only one harvests exclusively from privately owned land. Given the lack of information on volumes harvested from privately owned areas, the total volumes harvested from privately owned areas cannot be assessed.

4.2.10 It was estimated that in 2020, approximately 8,000 tonnes of wild seaweed were harvested (equating to about 50% of the maximum allowed tonnage under CES licence). This is likely to be an underestimate for several reasons. Information on the actual volume of seaweed harvested per business was sought during the consultation exercise in this study, but this information was not always provided (especially where a large range of species are being harvested but also due to commercial confidentiality), and not all businesses contacted engaged with the consultation. However, the outputs of the consultation suggested that (at that time), businesses were not harvesting wild seaweed at the maximum volumes allowed under the CES licence. In addition, tonnages harvested from private land are not included.

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Table 4. Species, method and maximum volumes of seaweed harvest under CES licence per annum in Scotland and seaweed product categories based on the consultation undertaken as part of this study (n=9)

Species	Harvest method	Max. harvest tonnages under CES licence (tonnes) *	Product category
Ascophyllum nodosum (egg wrack)	Hand (incl. rake and nets from vessel) Mechanical using modified vessel	11,520	Horticulture; Animal feed; Human food; Bio-actives (cosmetics, nutraceuticals)
Fucus vesiculosus (bladder wrack)	Hand	249	Human food; Bio-actives (cosmetics, nutraceuticals)
Fucus serratus (serrated wrack)	Hand	201	Human food; Bio-actives (cosmetics)
Himanthalia elongata (thong weed)	Hand	101	Human food
Laminaria digitata (oarweed)	Hand	413	Human food; Bio-actives (cosmetics)
Laminaria hyperborea (tangle / cuvie)	Hand	51	Human food
Saccharina latissima (Sugar kelp)	Hand	10	Human food
Alaria esculenta (dabberlocks)	Hand	62	Human food
Porphyra sp. (laver species)	Hand	10	Human food
Palmaria palmata (Dulse)	Hand	56	Human food; Bio-actives (cosmetics)
Osmundea pinnatifida (Pepper dulse)	Hand	2	Human food
Chondrus crispus / *Mastocarpus stellatus* (Carrageen)	Hand	8	Human food; Bio-actives (cosmetics)
Ulva sp.	Hand	8	Human food; Bio-actives (cosmetics)

Species	Harvest method	Max. harvest tonnages under CES licence (tonnes) *	Product category
* Maximum consented harvest volume per species under Crown Estate Scotland licence was provided by CES. It does not account for species harvested on private land not owned by CES, for which the volumes harvested are not known.			
Note: The CES licensed harvest tonnages only represent the consented maximum volumes of seaweed to be taken from CES-owned foreshore (i.e. approximately 50% of foreshore in Scotland). Such licences are only required for licensees who intend to harvest tens or hundreds of tonnes of seaweed per annum and the maximum licensed tonnages are based on stock and sustainable harvest assessments supplied by the licensee (Appendix A). The tonnages presented therefore do not necessarily represent actual harvested volumes and do not account for species harvested on private land not owned by CES, or species harvested at smaller scales. Whilst information on the volume of seaweed harvested per business was sought during consultation for this study, volumes per species were not always provided and thus are not presented here. Furthermore, not all seaweed-related businesses that operate in Scotland were able to input into the study.			

Source: Data provided by Crown Estate Scotland (May, 2020) and stakeholder consultation

Current seaweed cultivation activity in Scotland

4.2.11 At the time of the consultation (Feb to May 2020)[15], there was only one company commercially cultivating seaweed in Scotland. No information regarding the species cultivated or the tonnage harvested was available. The farm is owned by a vertically integrated company that acts as the producer organisation, intermediary and end-user selling products for human consumption (Stanley et al., 2019).

4.2.12 There were also two experimental seaweed farms off the west coast of Scotland (the Cutter's Rock farm in the Sound of Kerrera and the Port A'Bhuiltin in the Forth of Lorne between the mainland and the island of Lismore) managed by the Scottish Association of Marine Science (SAMS). The main species cultivated currently are *Alaria esculenta*, *S. latissima* and *L. digitata*. Biomass harvested from the Port A'Bhuiltin farm in excess of that utilised for R&D may be available to feed into the current supply chain, although information on the tonnages currently harvested were not divulged for confidentiality reasons.

4.2.13 Hence, the baseline review indicated that some seaweed cultivated in Scotland is currently being used within the supply chain in Scotland, albeit in low volumes.

4.2.14 Information from the consultation indicated that there are companies in the seaweed value chain in Scotland who are keen to utilise seaweed cultivated in Scotland in their products, although currently the high cost of farmed seaweed (compared to wild harvested seaweed) does not make this economically feasible. However, these supply chain businesses are currently able to source seaweed from the global market (i.e. outwith Scotland) and hence are neither

[15] Data supplied Marine Scotland Licensing Operations team on 26.04.21 showed that there are now nine licensed seaweed farming sites and another six marine licence applications of seaweed farms being processed. However, it is not known how many of these farms are currently operational.

impacted by the lack of Scottish cultivated seaweed nor currently directly driving the demand for cultivated seaweed in Scotland (Stanley et al. 2019).

4.2.15 The primary species of interest to cultivate in the immediate future are *S. latissima*, *A. esculenta* (both of interest for the food market) and *L. digitata*. Other species that stakeholders expressed an interest in cultivating included green seaweed species (e.g. *Ulva lactuca*, *Ulva linza* and *Undaria pinnatifida*) and higher value red seaweeds such as *P. palmata*, *Osmundea pinnatifida*, *Chondrus crispus*, *Gracilaria* spp. (*G. gracilis*), *Gelidium* and *Gracilariopsis* longissimi, although many of these species may be better suited to cultivation in tanks on land. Whilst such red seaweed species are considered high value species and would only be required to be cultivated in small volumes (e.g. for use within the cosmetics industry) tank-based cultivation has high energy demands (for example to maintain specific temperatures or constant bubbling (tumble culture), requiring these costs to be offset.

4.2.16 The industry's and wider stakeholders' opinions on the key drivers and constraints to developing the seaweed farming sub-sector in Scotland is presented in Section 5.

Location of seaweed-based businesses in Scotland

4.2.17 The majority of seaweed-based businesses, which harvest seaweed in Scotland, or currently utilise wild harvested seaweed from Scotland, are located on the west coast of Scotland (primarily within the Local Authority areas of Comhairle nan Eilean Siar and Argyll and Bute, but also the west coast of the Highlands) (Table 5). A lesser number of businesses are based on the east coast (within the Highlands and Fife), whilst one is based outwith Scotland (in England).

4.2.18 The majority of businesses that harvest seaweed do so within the same locale in which seaweed is processed and/or their business is located. However, a few harvest or source seaweed outwith the immediate locale in which they are based; this includes harvesting taking place in the Western Isles and Orkney. A few businesses that rely on specialist supply chain companies to

manufacture or package finished seaweed products also use other businesses located outside of Scotland (see Figure 2).

4.2.19 The one established commercial seaweed farm in Scotland at the time of consultation (2020) is based within the Local Authority area of Argyll and Bute. Most of the seaweed cultivation activity in the pipeline (i.e. currently seeking consents) would predominately be located off the west coast of Scotland (given the more sheltered nature of the coastline) although there is also interest off the east coast (based on wider stakeholder input).

Table 5. Location of businesses using wild harvested seaweed from Scotland

Local Authority Area	Number of businesses
Argyll and Bute	4
Comhairle nan Eilean Siar	5
The Highlands	2
Fife	1
England	1

Other actors in Scotland

4.2.20 A wide range of other organisations are also involved in supporting and developing the seaweed-industry in Scotland, although their core business does not relate to seaweed. Such actors are involved in R&D (e.g. SAMS, The James Hutton Institute, North Atlantic Fisheries College), Innovation (e.g. SAMS, IBiolC, Scottish Aquaculture Innovation Centre (SAIC)) and Enterprise (e.g. Highlands and Island Enterprise, Scottish Enterprise) (see Stanley et al. 2019). Whilst a monetary value of such actors has not been incorporated into the economic evaluation of the current seaweed-based sector in Scotland (presented in Section 4.3 below), where information was obtained from such stakeholders during the consultation it has been incorporated into the baseline review of the Scottish seaweed-based industry (above) and in the development of plausible scenarios for the seaweed-based sector in Scotland (Section 6).

4.3 Current industry baseline economic analysis

Approach

4.3.1 The following economic analysis is based on the information obtained through interviews with seaweed-based companies, supplemented by additional information sources included the activity mapping exercise undertaken for the Seaweed Review Steering Group and a review of company accounts via Companies House[16].

4.3.2 The economic analysis is divided into the following aspects:

- Scale and viability of existing companies, including turnover, profit and projected growth;
- GVA based on difference between turnover and operational costs; and
- Employment based on full-time equivalents currently employed;

4.3.3 The economic analysis is presented by the following product 'groupings' where possible[17]:

- Food for human consumption;
- Animal feed;
- Horticultural products;
- Bioactive products for the cosmeceutical and pharmaceutical industries; and
- Innovative applications or biotechnology.

[16] The Companies House Register is available on the Gov.UK website.

[17] However, in some cases, it was not possible to report monetary estimates by product group due to confidentiality issues arising when there are a small number of companies involved. Where this is the case, quantitative data for that specific product group is not presented and a more aggregated summary is given, combining more than one product group to protect confidentiality

4.3.4 Businesses which are not yet trading commercially were not included in the current economic analysis other than for enabling the number of businesses per product group to be estimated, although their potential value and growth potential were considered in the projected future scenarios (Section 6).

Limitations

4.3.5 A small number of additional companies involved in seaweed harvesting and/or cultivation were identified but were not interviewed. Information on these companies (e.g. from Companies House) was very limited. Hence it is known that some companies who generate turnover from seaweed have not been captured within this analysis and not included under the baseline (for example, if they did not engage, did not provide quantitative information and/or no information was available from Companies House), and as such the estimated turnover and GVA are **likely to be an under-estimate and should be regarded as indicative**. Should this be the case, the impacts under the BAU and the High Growth Scenario are also likely to be an underestimate. Yet, these are the best possible at the time of writing with the range of information available (see Table 6, below).

Scale and viability of existing companies

4.3.6 The scale of the current market is based on the number of companies operating in a product category, turnover, profit and growth over the past three years (2017-2020). Growth potential is also considered, as reported by companies during the interviews or taken from information submitted to Companies House. The results are provided in Table 6.

4.3.7 Nine companies were identified that are producing **human food,** all of which were identified as being micro-entities or small companies under the Companies House (2019) definitions. Five companies produce only human food, while four others also produce other product types.

4.3.8 There are seven companies producing **bio-actives**. Of these, three produce cosmetics, three produce nutraceuticals and one produces both. Four of these

companies also produce human food. As with human food, all of these companies are micro-entities or small companies.

4.3.9 For **horticulture** and **animal feed**, there were two companies that reported producing these, both of which are relatively large-scale harvesters and processors. As there are only two companies identified for these products, no quantitative data is presented for this category to protect commercial confidentiality.

4.3.10 Turnover varies by type of product (Table 6) but is also highly variable within any one product category. Average (mean) turnover for companies involved in production of **human food** is around £210,000 per year (median £191,000)[18]. Average (mean) profits reported are around £34,000 per year (median £21,000)[19]. Some companies reported losses (which have been excluded from the mean profits) for example due to investment in equipment.

[18] Based on reported and estimated turnover from 6 companies (estimated turnover includes where product value and tonnage was given). The two companies that did not provide turnover data (or had no turnover in the case of the start-up) are not counted in the mean value.

[19] Based on reported or estimated profits from 4 companies (estimated profits per product category are based on an assumed turnover by product category, with profit then taken as the same percentage as for the overall company information).

Table 6 Scale of markets by product type

Product category	No. of companies[1]	Turnover		Profit		Forecast growth[2]
		Mean	Median	Mean	Median	
Human food	9	£210,000	£190,000	£34,000 (but some companies report losses)	£21,000	↑
Animal feed	2	Confidential		Confidential		→
Horticulture	2	Confidential		Confidential		↗
Bio-actives (cosmetics, pharmaceuticals, and nutraceuticals)	7	£87,000	£125,000	£15,000	£13,000	↑
Hydrocolloids	None in Scotland	-		-		-
Biofuels	None identified	-		-		-
Innovative/ biotechnology	2	Not applicable		Not applicable		↑
Key: ↑	Growth expected to at least double in next few years					
↗	Growth expected but to be less than double in next few years					
→	Little or no growth expected, expected to remain more or less at the same level					
↘	Potential reduction in production expected					

[1] Companies producing more than one product category are counted for each category. Thus the total number of companies recorded in the table exceeds the total number of producers identified: 13. Turnover has been allocated to the different product categories to avoid double counting. Number of companies includes both those interviewed and those identified as producing seaweed-based products based on publicly available information. Note information on turnover and/or GVA was not available for all of these companies, hence, total turnover is likely to be an under-estimate

[2] Forecast growth based on information provided by the businesses consulted and presented as a general trend to protect confidentiality

4.3.11 For **bio-actives**, average (mean) turnover is estimated at £87,000 per year (median £125,000)[20] with profits estimated at £15,000 per year (median £13,000)[21]. None of the companies reported losses.

4.3.12 For **innovative products and biotechnology**, there is some development that is on-going through start-ups. These businesses are at an early stage so no turnover or profit information is available.

Gross Value Added

4.3.13 Overall turnover across all companies where data are available (or can be estimated) is around £4 million with an average (mean) turnover of £500,000 and a median of £270,000 per company[22]. Gross Value Added can be extrapolated across the remaining companies, based on average GVA for small-scale, medium-scale and large-scale companies[23] but ignoring start-ups as these are not currently generating any GVA.

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[20] Based on reported and estimated turnover from 4 companies. No additional information product value or tonnage was provided so turnover for the remaining companies cannot be estimated.

[21] Based on reported or estimated profits from 3 companies (approach to estimated profits as for human food)

[22] Based on reported (and estimated) data for 8 companies (note this excludes start-ups). Turnover ranges from less than £10,000 per year to more than £1 million per year, hence the large difference between the mean and the median. The number of companies included in the analysis is 8 as this includes some companies producing more than one product type (hence the number is not the sum of the companies across the human food, bioactives, animal feed and horticulture product types)

[23] Extrapolated based on 25% GVA from turnover for small-scale, 20% GVA from turnover for medium-scale and 10% from turnover for large-scale companies.

4.3.14 **Total GVA from the seaweed industry in Scotland** can then be estimated at **£510,000 per year**, with this based on weighted average GVA of 13% of turnover. This is expected to be an under-estimate as some companies producing seaweed-based products may not be captured and turnover data was not available for all due to gaps in both the information provided via interviews and from publicly available data such as from Companies House. This compares with GVA in Scotland (for 2018) of £485 million for fishing and aquaculture, £1,609 million for manufacture of food products and £1,036 million for manufacture of pharmaceutical products (ONS, 2019).

Employment

4.3.15 Ten of the companies responding to the survey reported the number of employees. This gives a total of 59 employees across all companies that provided data, with an average (mean) of 7 per company and median of 4 employees. There is a significant range with some companies having no staff other than the owners, up to a maximum of 20.

5 Drivers and constraints to the future seaweed-based industry in Scotland

5.1.1 This section provides an overview of stakeholder opinion on how the seaweed industry may develop in Scotland over the next 20 years and the key drivers of, and constraints to, that development. The information is summarised from 22 interviews and is presented in an aggregated and anonymised format to protect confidentiality.

5.1.2 The outputs of the consultation indicated that there was a strong desire for the sustainable development of the seaweed-based sector in Scotland and indeed for Scottish seaweed to become a 'global brand'. Many businesses consulted expressed the desire to source all required raw material from Scotland, in addition to using supply chain companies and services also available within Scotland. It was suggested that the key to scaling up the seaweed-based sector would be to add value in Scotland rather than selling raw material to other countries.

5.1.3 Although various constraints to the development of seaweed cultivation in Scotland were described (see Table 8), in general businesses and wider stakeholders felt that seaweed cultivation had to be part of the sector's future in Scotland, in part because some felt that large-scale harvesting is probably not sustainable, but also to enable diversification of seaweed species available and hence products and end uses.

5.1.4 There was a strong conviction amongst several stakeholders that there is a high demand (within and beyond Scotland) for a consistent supply of high-quality cultivated seaweed e.g. from multinational corporations. However, stakeholders also highlighted the current disconnect between the supply of, and demand for, cultivated seaweed (i.e. that the required supply couldn't be achieved without the demand and *vice versa*).

5.1.5 In general, established businesses in Scotland that currently use wild harvested resource are interested in cultivating seaweed. Indeed, some have undertaken R&D and/or pilot trials to assess the potential to do so. However, these

stakeholders indicated they were not pursuing this further at this time due to cultivation not currently being economically viable, a view shared by many of the stakeholders interviewed.

5.1.6 One stakeholder's opinion was that cultivating seaweed is not currently economically viable without financial support (unless undertaken within a vertically-integrated company in which the value is added in the processing, potentially offsetting the higher cost of the cultivated seaweed). Underlying elements considered to contribute to this barrier included the start-up investment cost, cost of seeded lines (currently costly in Scotland compared to other areas in Europe where the industry is more established e.g. the Netherlands), the labour intensive process (i.e. manual deployment of lines and harvesting), a lack of defined markets for the species which can currently be cultivated, the relatively low value of species currently farmed and the need for R&D to enable cultivation of higher value species (for example *Palmaria*, *Gracilaria*).

5.1.7 Several stakeholders consulted felt that economic viability (profitability) could only be achieved through farming at an industrial (large) scale. Such economies of scale would require mechanisation with respect to deployment of seeded lines and harvesting, and hence would require high levels of capital funds/investment. However, some stakeholders felt that such large-scale seaweed farms, with bigger structural capacity, would "bump up" against social licence[24] i.e. not be acceptable to coastal communities. Numerous stakeholders stated that their vision for the sector in Scotland would be for numerous small-

[24] Social licence is an industry-coined term relating to the relationship between industries and local communities in circumstances where the activities have social and environmental costs. It is described as an on-going relationship between a host community and an organisation (industry, Non-governmental organisation (NGO), business) where the organisation is held to certain standards set by the community, in exchange for acceptance by the community (Stanley et al. 2019 and references therein).

scale farms, potentially functioning in a co-operative way. A current initiative is underway in Scotland to form a 'Scottish Seaweed Cooperative'[25] to facilitate co-ordination and collaboration between stakeholders (e.g. cultivators, intermediaries, markets), helping them to scale-up and increase value through processing and to be able to respond to market demand. It was also noted that whilst local communities may be interested in establishing seaweed farms, they would not necessarily have the required technical knowledge and hence would likely need the support of 'intermediaries' with expertise in seaweed cultivation and aquaculture systems.

5.1.8 There was a variety of opinions about the potential future importance of seaweed cultivation for the sector going forward – one opinion was that seaweed cultivation would not replace wild harvesting as a source of raw material, whilst another stakeholder (from outside of Scotland) felt that if sufficient scales of cultivation could be achieved, cultivated raw material may be able to compete with wild harvest sources within 7 to 8 years. Another felt that the focus should be on creating high value products from the wild seaweed that is currently harvested. Indeed, consultation indicated that many stakeholders felt that sector growth in the form of expansion of production of existing seaweed-based products and development of new products could be met by raw material provided through wild harvesting (see Tables 10-13; Section 6).

5.1.9 It was also highlighted that the current wild harvesting businesses that exist in Scotland (on which almost the entire commercial sector is currently based) are important with respect to the socio-economic benefits that they provide e.g. the levels of local employment in remote and island communities. However, the future of this industry was considered to depend upon the proportionate regulation of access to the wild resource (ensuring security of supply) and timely determinations on consent (CES licence) to wild harvest, enabling

[25] Scottish Seaweed Cooperative: White Paper, 23 July 2020 (In press). Supplied by the International Blue Cooperative, 31 July 2020

businesses to plan capital investments and invest in product development research. Stakeholder opinion on current regulation of wild seaweed harvesting included that NatureScot (formerly Scottish Natural Heritage (SNH)) oversight of the process was too restrictive and that more guidance was required around allowable wild harvesting tonnages which appeared to be changeable. There was also concern from a few wider and industry stakeholders that any changes to the regulations around wild harvesting of seaweed (and particularly the mechanical harvesting of seaweed as currently undertaken in some locations) could impact or threaten that sector. One wider stakeholder considered that a clear regulatory process was required, particularly with respect to large-scale wild harvesting.

5.1.10 Table 7 and Table 8 provide summaries of seaweed-business and wider stakeholder views of the key drivers of, and constraints to, the potential future growth of the Scottish seaweed-based industry. Where a driver or constraint is specific to wild harvesting or cultivation it is specified in the tables. The influence of these drivers and constraints on the projected future scenarios is described in Section 6 and discussed further in Sections 8 and 9.

Table 7 Key drivers of the seaweed-based industry in Scotland

Driver	Description
The blue economy / circular economy	Sustainable use of marine resources. Circular economy – interest in use of whole seaweed for multiple products, with no waste (i.e. create value chain in Scotland to use all seaweed)
Employment	Job creation for coastal communities
Consumer preference	Consumer awareness and interest in sustainable sources of healthy food, particularly plant based.
Market demand	Growing demand for seaweed in an increasing variety of products, as well as demand for seaweed by large companies as part of their corporate sustainability goals. Stakeholder perception of the existence of big market demand for a consistent supply and quality of cultivated seaweed
Sustainability / environmental impacts (seaweed cultivation)	Strong desire for sustainable development of the industry. Some stakeholder concerns about the sustainability of large-scale wild harvesting (e.g. of kelp) and regulator concerns about limited UK evidence on impacts. Cultivation of seaweed may be an alternative where larger volumes required, subject to economic viability and environmental impacts
Provenance / global brand	High profile of Scottish food and drink globally would facilitate promoting provenance of Scottish seaweed and in sourcing seaweed cultivated in Scotland for inclusion in products.

Source: stakeholder consultation

Table 8 Key constraints to the seaweed-based industry in Scotland

Constraint	Description
Investment and access to finance	The seaweed-based sector faces the same challenges as other types of start-up business, except the challenges are exacerbated by seaweed being a novel product, for example in relation to lack of knowledge of seaweed markets. The cost of premises and equipment in the required locations (close to production sites), which are often remote, is a challenge. There is a lack of finance available for equipment and to scale-up.
Need for supply chain / infrastructure development	Certain specialist companies currently used by the sector (e.g. for some forms of packaging or secondary processing) are located outside Scotland. Other difficulties raised included the availability of staff at certain times of the year, the availability of staff with the required skills and the lack of other infrastructure requirements (e.g. landing sites) particularly in remote/island locations.
Social licence	Lack of social licence for the level of wild harvesting required to supply some high value sectors e.g. biorefining of seaweed for multiple high value products, and potential lack of social licence for large-scale cultivation.
Regulation and licensing	Wild harvesting: The future of the industry is dependent on clear guidance and proportionate regulation of access to wild seaweed resources, with timely determination of consent (CES licences) to wild harvest. This would provide the confidence/ability to plan capital investments, develop facilities and invest in science-based product development to create new markets and customers. The current time taken to receive consent can result in the loss of customers. Cultivation: The time taken to receive a marine licence for cultivation was raised as a potential issue for the industry.
Economic viability (cultivation)	Seaweed cultivation is not currently considered economically viable (unless undertaken within a vertically-integrated company in which the value is added in the processing, potentially offsetting the higher cost of the cultivated seaweed). Factors influencing the economic viability were cited as the start-up investment cost, the cost of seeded lines in Scotland (cheap in Europe where supply more developed); the relatively low value of species that can currently be cultivated at sea; the labour intensive process, the large scale of cultivation required to achieve viability (for which there may be a lack of social licence) and the potential to need mechanised seeding and harvesting to achieve these scales.

Constraint	Description
Limited range of species currently cultivated	Currently only a limited number of seaweeds can be successfully cultivated. R&D is required to enable cultivation of higher value species such as *Palmaria palmata*. It is not commercially viable to cultivate *Laminaria hyperborea* for biorefinery purposes as it takes 4-5 years to reach the required growth stage and the sought-after biochemical properties arise from high energy environments in which it naturally occurs.
Market supply and demand (cultivation)	Lack of clarity regarding the markets for the species that can currently be cultivated and the disconnect between potential supply and demand (both projected to be large but the difficulty of one developing without the other)
Disease (cultivation)	Potential problems with disease and pests for cultivated seaweed[26] (particularly monocultures), as has recently caused a decline in seaweed production in Asia.
Available marine space for developments (cultivation)	A potential issue if large-scale farms are to be developed.

Source: Stakeholder consultation

[26] In general, all types of aquaculture (i.e. finfish, shellfish and seaweed aquaculture) may be affected by disease and/or pests. Stanley et al. (2019 and references therein) describe how the issue of disease and pests is intensified for cultivated seaweed by a reduction in genetic diversity associated with the domestication of wild seaweed species making crops more susceptible to abiotic stressors, diseases and parasites, potentially resulting in large reductions in yields. Furthermore, farmed seaweed may also act a reservoir for disease which could impact natural populations.

6 Projected future growth scenarios

6.1 Overview

6.1.1 This section describes the development of the projected future growth scenarios for the seaweed-based industry in Scotland[27]. The scenarios were developed through consideration of the growth aspirations of the sector (from consultation), key sector drivers and constraints (Section 5), and market trends and competition from comparable countries (Appendix C), which were used to develop projected future scenarios for key existing products in Scotland and those most likely to develop (described further below).

6.2 Approach

6.2.1 Two projected future scenarios were developed based primarily on the information provided during consultation, including business and wider stakeholder aspirations and how it was envisaged that the sector could grow (see Section 5):

- Business as Usual – in which the sector continues to grow and raw material is supplied by wild harvesting of seaweed within Scotland; and
- A higher growth scenario – in which seaweed cultivation in Scotland develops, providing additional raw material to that from wild harvested seaweed, enabling a higher growth of the component industry sub-sectors and includes the development of biorefinery technology which utilises cultivated seaweed.

6.2.2 The tonnage of raw seaweed material required to underpin the projected growth of the sector in each scenario was calculated through applying the

[27] For the purposes of this study, the potential for growth and development of the Scottish industry has been considered within the current legislative and regulatory framework for seaweed wild harvesting and cultivation (described in Appendix A)

projected sector growth rates (see Table 15) to the estimated volume of wild seaweed harvested in 2020 (8,000 tonnes) and extrapolating the volume in 2040 (see Table G1, Appendix G for the projected annual production volumes per annum to 2040).

6.2.3 It was assumed that in both scenarios, the maximum consented volume of seaweed that could be wild harvested under Crown Estate Scotland consent is 30,000 tonnes (i.e. double the maximum consented volume in 2020 for all species combined).

6.2.4 In the BAU scenario it was projected that 25,000 tonnes of raw seaweed material per annum would be required to support the projected sector growth in 2040 and it was assumed that all of the raw material would be supplied via wild harvesting.

6.2.5 In the Higher Growth scenario, it was projected that 54,000 tonnes of raw seaweed material per annum would be required to support the projected sector growth in 2040. This volume was assumed to comprise 30,000 tonnes of wild harvested seaweed (the maximum consented volume for wild harvesting; all species combined) and 24,000 tonnes of cultivated seaweed. The latter was considered sufficient to supply the biorefinery requirements in this scenario.

6.2.6 Table 9 further describes the high-level assumptions and rationale underpinning the two scenarios.

Limitations

6.2.7 Given the data gaps described in the baseline economic analysis (Section 4.3), the high levels of uncertainties around future markets and trends (including in relation to the current COVID-19 situation and the recent departure of the UK from the European Union), the constraints facing the cultivation sector (raised by the stakeholders), as well as the assumptions described in Table 9, the projected scenarios are necessarily indicative (low confidence).

Table 9 Projected scenario rationale and assumptions

Scenario	Rationale	Assumptions
Business as Usual (BAU)	The current sector (based on 2020 data and consultation) is almost entirely dependent on the wild harvesting of seaweed. The majority of companies that engaged with the study indicated an intention to expand production and develop new products, particularly high value products in response to existing and emerging markets, from wild harvested resources. In general businesses felt that the additional wild seaweed resource for such expansion was available (including in part due to some products requiring only low volumes of seaweed to produce high value products). Furthermore, the main species harvested from the wild is *Ascophyllum nodosum*, an intertidal species which is not cultivated. At the time of consultation (2020) stakeholders advised that there was no commercial scale farmed seaweed production (whilst some farmed seaweed was entering the supply chain, the tonnages were small). The BAU scenario is therefore based on future sector growth through increased production of existing seaweed products and the development of new high value products, with raw material over the next 20 years being supplied solely by wild harvesting within Scotland. The calculation of the projected volumes of wild harvested seaweed required between 2021 and 2040 are presented in Appendix G.	'Commercial scale' farming of seaweed is not established and no substantial tonnage of farmed seaweed enters the supply chain (for the purposes of the scenario – farmed tonnage is assumed to be zero). Increased raw material requirements can be met through sustainable harvesting of wild stocks between 2021 and 2040. The main species harvested by volume in 2040 will still be *Ascophyllum nodosum*, although a wide range of other species will also be wild harvested (See Tables 10-14). **Raw material requirements 2040**: 25,000 tonnes **Raw material source 2040**: All wild harvested (under consent) within Scotland (no imported raw material).

Scenario	Rationale	Assumptions
Higher Growth	There is a strong desire for the development of seaweed cultivation in Scotland and for developments in biotechnology that enable multiple high value products to be extracted from seaweed by companies based in Scotland. The calculation of the projected volumes of wild harvested and farmed seaweed required between 2021 and 2040 are presented in Appendix G.	The constraints facing the cultivation sector are sufficiently overcome to enable substantial development of the industry. The annual tonnage farmed is sufficient to feed into a novel biorefinery process, as well as some of the other product groups (e.g. food etc). The main species wild harvested by volume in 2040 will still be *Ascophyllum nodosum*, although a wide range of other species will also be wild harvested (See Tables 10-14). The main species cultivated by volume are *Saccharina latissima*, *Laminaria digitata* and *Alaria esculenta,* although there is diversification of the species that can be cultivated by 2040. **Raw material requirements 2040**: 54,000 tonnes

Scenario	Rationale	Assumptions
		Raw material sources 2040: - 30,000 tonnes wild harvested seaweed within Scotland (consented by Crown Estate Scotland wild harvest licence); - 24,000 tonnes seaweed cultivated in Scotland(consented by Marine Licence); - No imported raw material.

6.2.8 The product groups that were included within the scenarios were:

- High value food products for human consumption;
- Animal feed;
- Horticultural products;
- Bioactives for the nutraceutical and cosmeceutical industries; and
- High value products from a biorefinery approach (in the high growth scenario only; see below).

6.2.9 The product groups scoped out of the future scenario development were:

- Biofuels – due to consensus amongst stakeholders that this is not likely to be a viable option over the next 20 years (except potentially in relation to relatively small-scale production as a component of a zero waste biorefinery approach); and
- Hydrocolloids – no indication was given from the consultation that any businesses intended to focus solely on producing hydrocolloids in Scotland (any such products arising from biotechnology processes such as biorefining are captured under the biotechnology/innovation product category).

6.2.10 In developing the scenarios for each product group, the following factors were considered based on information from the reviews of the current Scottish and International sector baselines and stakeholder consultation:

- The sector growth aspirations by product group;
- Confidence in the sector's aspiration e.g. based on information provided in the interviews, for example relating to capital investments, markets (not disclosed);
- General evidence relating to market demand (e.g. from trade analysis sources);
- The value of the product group (based on the value of products in Cefas 2016);
- The existence of competition for the same markets (using information from Section 3);

- The scale of raw material (seaweed) required to meet growth aspirations and the likely availability of the raw material;
- Processing capability and supply chain requirements in Scotland; and
- The key constraints to the sector (product group).

6.2.11 Table 10 to Table 14 summarise the information that was considered in developing the projected scenarios for each of the product groups listed above. To protect commercial confidentiality full details underpinning some judgements have not been disclosed (particularly where the number of business in the component sector is fewer than 5, and with respect to sector aspirations and evidence underpinning confidence in growth targets). Table 15 describes the final projected growth scenarios for each product group.

Table 10 Scenario development for the food sector

Factor	Information for scenarios
Types of products and markets	Snacks, condiments; beverages; food grade powders. Range of local, UK and global markets
No. businesses identified in Scotland*	9
Scottish sector growth aspirations (confidence)	Nearly all companies consulted (n=7) projected growth (projected increased turnover ranged from 2 to 5 times in next 2-3 years) between 2020-2023** based on demand from existing markets and new markets. Most intended to expand their product range. (confidence: medium – based on information about markets)
Wider evidence of market demand	In general there has been a recent increase in demand for plant-based food products (e.g. increasing vegan trend). ValgOrize, 2019 states that the European market for seaweed food products is growing annually by an estimated 7-10%.
Product value category	Assumed speciality products (£5-1,000/ kg))
Competition from comparable countries	Yes, European seaweed producers (mainly from France and Spain) supply 25% of the market for sea vegetables in Europe. France is the major producer of dulse for this market (90% of market) and Spain the leading producer for *Undaria pinnatifida* (wakame). However, it was assumed that this competition would not exclude Scottish products from the market, with some products already penetrating global markets. Furthermore, this product group could potentially benefit from promotion of Scottish branding / provenance (e.g. from an environmental standards/water quality perspective), due to high profile of Scottish food and drink globally.
Raw material requirements (species; tonnages)	Current species utilised: *Ascophyllum nodosum* (egg wrack); *Fucus vesiculosus* (bladder wrack), *Fucus serratus* (serrated wrack); *Laminaria hyperborea* (cuvie); *L. digitata* (oarweed); *Chondrus crispus* (Irish moss); *Palmaria palmata* (dulce); *Osmundea pinnatifida* (pepper dulce),

Factor	Information for scenarios
	Saccharina latissima (sugar kelp); *Alaria esculenta* (dabberlocks); *Porphyra* (laver); *Ulva linza*; *Ulva Lactuca; Himanthalia elongata* (thong weed); Potential species of interest/importance over the next 20 years: *Gracilaria* and *Gelidium* species; *Gracilariopsis longissimi*. Median tonnage: disaggregated information not available
Raw material availability	Additional seaweed resource would be required; this would be supplied by wild harvesting and all interviewees felt that the additional resource was available. Some businesses would like to cultivate seaweed to include in their products but stated this is not currently economically viable.
Processing capability available in Scotland	Yes, most companies have their own processing capabilities (although investment for scale up an issue; see below)
Constraints to growth	Packaging costs (if want environmentally friendly packaging); Supply chain logistics in remote locations; Market demand (education will help generate); Complexity of consent process and timescale of decisions (for consent for wild harvest (CES licence) and cultivation (marine licence); multiple stakeholder opinion); Appropriate premises (size and cost) for scaling up close to shore; Lack of finance and capital costs for scale-up.
* Note, not all businesses identified contributed to the consultation ** Business aspirations prior to COVID-19 which adds another element of uncertainty	

Table 11 Scenario development for the feed sector

Factor	Information for scenarios
Types of products and markets	Dried milled seaweed; Scottish and global markets
No. businesses identified in Scotland	2
Scottish sector growth aspirations (confidence)	Assumed that there is no substantial change in market demand (low confidence).
Wider evidence of market demand	No evidence was found relating to future trends in market supply and demand for seaweed-based animal feed products, although some wider stakeholders thought this could be a high growth area in the short-term (no evidence provided). This may relate to the interest in the probiotic effects of macroalgae supplements in animal feed and its potential use in aquaculture feed (see Stanley et al. 2019). Although there is some evidence of potential benefits of including seaweed as part of animal/aquaculture feed, further research is required to better quantify these benefits as well as any potential adverse effects. The influence of cultivating seaweed (e.g. in relation to physical conditions, water quality and timing of harvest) on the chemical composition of seaweed species for inclusion in animal feed also requires further research (Stanley et al. 2019). As such, it has been assumed that feed would continue to be a 'staple' use for seaweed (as per its current application) with demand staying constant over the timescale of the scenarios.
Product value category	Assumed low value (c. £1/kg)
Competition from comparable countries	Yes e.g. France. No information/data sourced on the number of companies involved or market share. It has been assumed that if feed/feed ingredients can be produced at a competitive price, competition from other countries will not restrict this product sector in Scotland.

Factor	Information for scenarios
Raw material requirements (species; tonnages)	Primarily *Ascophyllum nodosum* (egg wrack); also *Fucus vesiculosus* (bladder wrack) Median tonnage: confidential
Raw material availability for growth of sector	Additional seaweed resource would be required if sector expanded; this would be supplied by wild harvesting and interviewees felt that this resource was available (although the potential for the resource to be constrained as the whole Scottish sector expands was noted)
Processing capability available in Scotland	Yes (businesses have their own processing facilities)
Constraints to growth	Clear guidance and proportionate regulation of access to wild seaweed resources, with timely determination of consent (CES licences) (multiple stakeholder opinion); Creation of required infrastructure (for new industry) Supply chain logistics (especially on islands); Skilled staff recruitment;

Table 12 Scenario development for the horticulture sector

Factor	Information for scenarios
Types of products and markets	Dried milled seaweed; other (confidential); Scottish and global markets
No. businesses identified in Scotland	2
Scottish sector growth aspirations (confidence)	Intend to expand to meet demand in current and new markets (medium-high confidence; based on confidential information provided during consultation)
Wider evidence of market demand	No evidence was found relating to future trends in market supply and demand for seaweed-based horticultural products, although one other business consulted (not currently in this category) stated they may diversify into horticultural products. Some wider stakeholders thought this could be a high growth area in the short-term (no evidence provided).
Product value category	Assumed added value (£1-£5/kg) to speciality product (£1-£1000/kg)
Competition from comparable countries	Assumed yes, although no information/data sourced on the number of companies involved or market share for this product group. It has been assumed that if horticultural products can be produced at a competitive price, competition will not unduly restrict growth of this product sector in Scotland.
Raw material requirements (species; tonnages)	Primarily *Ascophyllum nodosum* (egg wrack); Median tonnage: confidential
Raw material availability	Additional seaweed resource will be required with sector growth; this would be supplied by wild harvesting and interviewees felt that this resource was available (although the potential for the resource to be constrained as the whole Scottish sector expands was noted)
Processing capability available in Scotland	Yes (businesses have their own processing facilities)

Factor	Information for scenarios
Constraints to growth	Clear guidance and proportionate regulation of access to wild seaweed resources, with timely determination of consent (CES licences) (multiple stakeholder opinion);; Creation of required infrastructure (for new industry) Supply chain logistics (especially on islands); Skilled staff recruitment;

Table 13 Scenario development for the bioactives sector

Factor	Information for scenarios
Types of products and markets	Ingredients (e.g. dried milled seaweed) and finished products for nutraceutical and cosmeceutical products (e.g. skin care products, health supplements); Scottish, UK and global markets.
No. businesses identified in Scotland*	7
Scottish sector growth aspirations (confidence)	All companies project growth between 2020-2023** (projected growth rates not shown as only 2 businesses provided quantitative estimates), based on demand from existing markets and new markets. Most intended to expand product range (medium - based on information about market demand).
Wider evidence of market demand	Growth of the European food supplement market, including seaweed-based nutritional supplements, has been estimated to be between 6-7% per annum up to 2025 (e.g. CBI, 2018 (not specific to seaweed).
Product value category	Assumed range from added value (up to £5/kg) to nutraceuticals and cosmeceuticals (>£2000/kg)
Competition from comparable countries	Yes e.g. France (and other countries where cultivating red seaweeds in land-based tanks e.g. Portugal). No information/data sourced on the number of companies involved or market share. It has been assumed that if the seaweed ingredients/compounds etc can be produced at a competitive price, competition from other countries will not restrict this product sector in Scotland. Scotland may be able to benefit from promoting the provenance of its seaweed (e.g. from an environmental standards/water quality perspective) in more global markets or through local provenance for domestic markets.

Factor	Information for scenarios
Raw material requirement (species; tonnages)	*Ascophyllum nodosum* (egg wrack); *Fucus vesiculosus* (bladder wrack), *Fucus serratus* (serrated wrack); *Laminaria hyperborea* (cuvie); *L. digitata* (oarweed); *Chondrus crispus* (Irish moss); *Palmaria palmata* (dulse); *Osmundea pinnatifida* (pepper dulse), *Saccharina latissimi* (sugar kelp); *Alaria esculenta* (dabberlocks); *Porphyra* (laver); *Ulva linza*; *Himanthalia elongata* (thong weed) Median tonnage: disaggregated information not available
Raw material availability	Additional seaweed resource would be required; for 3 companies this would be supplied by wild harvesting: two felt this resource was available; one felt seaweed resources were generally constrained in Scotland (i.e. low standing stock compared to Norway). Two businesses looking to source 80-100% of seaweed from farms (i.e. cultivated seaweed)
Processing capability available in Scotland	Will need to invest as expand
Constraints to growth	Supply chain logistics in remote locations; Market demand; Clear guidance and proportionate regulation of access to wild seaweed resources, with timely determination of consent (CES licences) (multiple stakeholder opinion); Appropriate (size and cost) premises for scaling up close to shore; Speed of regional and government sector support (e.g. marine plan support)
* Not all businesses identified contributed to the consultation ** Business aspirations prior to COVID-19 which adds another element of uncertainty	

Table 14 Scenario development for other novel/innovative products

Factor	Information for scenarios
Types of products and markets	Some specific innovative products are in development in Scotland (no detail presented due to confidentiality) for Scottish, UK and global markets. Whilst it is not possible to know what novel and innovative products may be developed over the next 20 years, general examples may include: - Using seaweed as a feedstock for biotechnology processes that extract a range of high value products; - Novel applications within new industry sectors; - Replacement of substances (i.e. some platform chemicals) currently derived from oil refining
No. businesses identified in Scotland	2
Scottish sector growth aspirations (confidence)	Utilisation of seaweed cultivated in Scotland to enable development of a zero-waste circular economy in which new processes enable multiple products to be extracted from seaweed, including high value/innovative products (low confidence)
Wider evidence of market demand	In general, the demand for speciality horticultural, cosmeceutical, nutraceutical and pharmaceutical/medical products extracted from seaweed will continue to increase (e.g. Stanley et al., 2019).
Product value category	Assumed added value (£1-5/kg) to special applications (>£5,000/kg)
Competition from comparable countries	Yes, likely from both European countries and Asia. In Europe it has been suggested that the future product and market focus will be on biorefinery processes and by-product valorization (EU Seaweed Strategy, 2020). For example, in France, the company Algaia is developing a

Factor	Information for scenarios
	biorefinery approach to develop proprietary processes and products, whilst in Indonesia there is a company focussed on producing biodegradable and edible seaweed-based food packaging (although it is not clear whether this is a commercial enterprise yet (stakeholder input)). It has been assumed that countries which have access to the high volumes of seaweed required for industrial / biorefinery processes, whether from wild harvested or cultivated sources, will have a competitive advantage. For biorefinery products such as alginate, the low-quality alginate market is dominated by China and the high-grade alginate market is dominated by one company in Norway (wider stakeholder communication). It is assumed that the impact of this competition on Scottish businesses will relate to a range of factors such as the quality of products (including whether cultivated seaweed has the required chemical properties for the grade/quality of the intended products (see constraints)) and the ability to supply products at a competitive price and/or scale. In Scotland the latter will be influenced by the availability and cost of the raw material required for more industrial/biorefinery extraction processes.
Raw material requirements (species; tonnages)	Year-round reliable (constant) supply of suitable quality cultivated seaweed, with the appropriate biochemical properties (i.e. the same biochemical properties that wild harvested seaweed has). This will likely require diversification of the types of species that can currently be harvested to enable a continuous year-round supply of material, as well as further research into the properties of cultivated seaweed.
Raw material availability for growth of sector	Raw material availability will depend on the processes and products being produced. For example, the biorefining of seaweed to make multiple products requires volumes of cultivated seaweed that are not currently available.
Processing capability available in Scotland	If specialist processing is required, this will require development in line with requirements of the products developed.

Factor	Information for scenarios
Constraints to growth	Availability of the required volumes (tonnage) of cultivated seaweed at a price enabling economic viability or market competitiveness of the end product; Understanding of the effects of cultivation on the biochemical properties of seaweed (i.e. whether farmed seaweed has the same properties as wild harvested seaweed); Determinations for a marine licence to cultivate seaweed made in a timely manner (stakeholder opinion). Social license both for the scale of seaweed supply required and for the end uses Investment

Table 15 Descriptions of the projected growth scenarios for each product group

Product group	Business as usual	Higher growth scenario
Food	Growth of this product type is driven by increasing consumer demand relating to environmental concerns (increasing demand for plant-based food) and health trends (increasing awareness of nutritional benefits). The raw material (seaweed) continues to be sourced from wild harvesting, utilising the current species and developing new food products. Whilst access to finance/investment remains an issue for Scottish businesses, they continue to access new markets, and benefit from promoting the quality and provenance of Scottish seaweed as consumer awareness increases. Growth is assumed to be 5% per year over 20 years for existing companies. One new business is developed per year until 2030, then one new entrant every other year until 2040. Each new entrant takes 5 years to reach the current average turnover, then 5% growth p.a. thereafter.	Greater access to finance/investment for scaling-up production results in a faster growth rate. The raw material continues to be sourced from wild harvesting, although faster growth of the sector (e.g. arising from investment to expedite production scale-up, increasing market penetration) may contribute to market demand for cultivated seaweed, and enable businesses to incorporate some cultivated seaweed into products, despite higher costs compared to wild harvested seaweed. Growth is assumed to be 10% per year over 20 years for existing companies. One business is developed per year until 2030 then one new entrant every other year until 2040. Each new entrant takes 3 years to reach the current average turnover, then 10% growth p.a. thereafter.
Animal feed	Dried milled seaweed for animal feed / feed supplement is a low value product. Projected growth rates confidential	As per the BAU scenario

Product group	Business as usual	Higher growth scenario
Horticulture	Growth of this product type is driven by increasing demand in existing and new markets. The raw material (seaweed) continues to be sourced from wild harvesting, utilising the current species, although new higher value more specialised products are developed. The processing capability is developed and funded by the companies involved as required. The more specialised higher value products support high growth over the short-term (i.e. up to 2025), although it is assumed that this level of growth is not continued over the 20 year time scale due to possible ceilings on the maximum tonnage of seaweed that can be wild harvested (the main seaweed species utilised, *Ascophyllum nodosum* (egg wrack), cannot be cultivated). Projected growth rates confidential	As per the BAU scenario, growth of this product type is driven by increasing demand in existing and new markets and the raw material continues to be sourced from wild harvesting. As the seaweed-based industry expands in Scotland, public acceptance of sustainably managed wild harvesting increases, enabling new entrants or expansion of the current sector in other locations around Scotland. Projected growth rate confidential. Assumed one new business/plant is developed in other locations around Scotland every 5 years.
Bioactives	Growth of this product type is driven by increasing demand in existing and new markets. Raw material continues to be sourced primarily from wild harvesting, due to the main species utilised not being suitable for cultivation (e.g. *Ascophyllum nododusm;* egg wrack) or requiring cultivation in land-based tanks with	As per the BAU scenario, except in response to market demand growth is assumed to be 10% per year over 20 years for existing companies. In addition: 1 new entrant (microenterprise) is established in 2025, increasing to full turnover in year 2029, then 10% growth p.a. thereafter

Product group	Business as usual	Higher growth scenario
	associated high energy costs (e.g. red and green seaweed species). However, relatively low tonnages are required and in general this does not limit the growth of this product type. New specialist high value seaweed-based products/ingredients for the nutraceutical and cosmeceutical industries are developed. Growth is assumed to be 7% per year over 20 years for existing companies. In addition: 1 new entrant (microenterprise) is established in 2025, increasing to full turnover in 2029, then 7% growth p.a. thereafter 1 new entrant (microenterprise) in year 2030 increasing to full turnover in 2034, then 7% growth p.a. thereafter	Due to growth in the sector and associated increased demand, 1 new entrant (SME) is established in 2030, increasing to full turnover in year 2034, then 10% growth p.a. thereafter; 1 new entrant (microenterprise) in 2035, increasing to full turnover in year 2039, then 10% growth p.a. thereafter.

Product group	Business as usual	Higher growth scenario
Biotechnology	This sector is not included in the BAU scenario based on the assumption that the volume requirements for raw material (seaweed) that would be required is not available (via wild harvesting or cultivation).	This scenario assumes there are two major developments: i) biotechnological developments enabling multiple high value products to be extracted from seaweed, for example, via a biorefinery approach; ii) seaweed cultivation develops in parallel with the biotechnology, to enable the volume of raw material required to be supplied from seaweed farms. Assumed that one biotechnology business is operational by 2025; projected growth rates confidential.

6.3 Economic impact under the projected growth scenarios

6.3.1 The indicative projected growth rates under the two future scenarios were then applied to the baseline turnover, GVA and employment figures presented in Section 4.3 for each product group[28]. The resulting projected turnover, GVA and employment under the BAU scenario and the higher growth scenario are shown in Figure 4 and Figure 5.

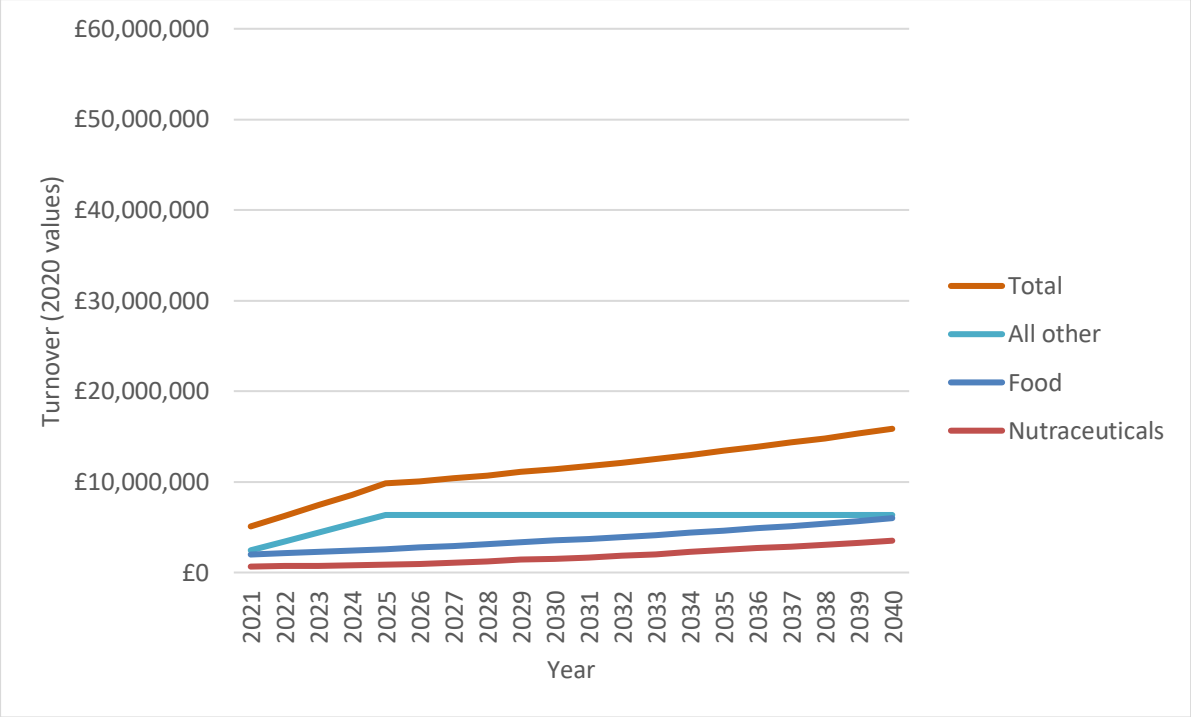

Figure 4 Business as Usual scenario

[28] Note due to the small number of businesses identified involved in the production of animal feed and horticultural products, the projections for these two product groups are not shown separately. Instead they are a component of the aggregated projected growth turnover, GVA and employment in each graph.

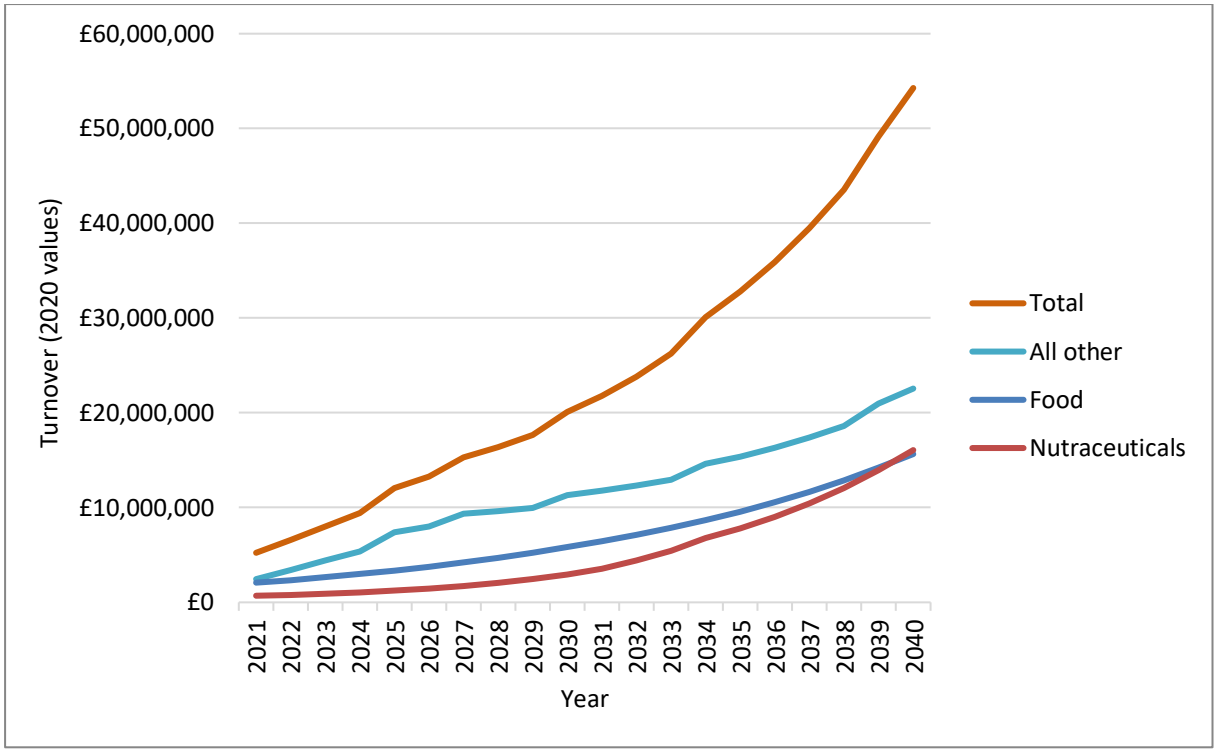

Figure 5 High growth scenario

6.3.2 Under the BAU scenario, food products have an average annual growth rate of 5.7%; Bioactive products have an average annual growth rate of 8.8%; all other products combined have an annual growth rate of 4.9% (individual growth rates confidential). Overall, the total turnover is estimated to increase by 210% over the whole period 2021-2040. Note that the average annual growth rates of each subsector over the period 2021 – 2040 differ to the assumed growth rates presented in Table 15 because of projected new entrants into the market, as described in Table 15.

6.3.3 Under the Higher Growth scenario, food products have an average annual growth rate of 10.6%; Bioactive products have an average annual growth rate of 17%, All other products combined have an annual growth rate of 11.7%. Overall, the total turnover is estimated to increase 937% over the whole period 2021–2040. As for BAU, the overall subsector growth rates differ from the annual assumptions for individual businesses and there are year-to-year differences in growth rates because of projected new entrants into the market. Note that the average annual growth rates of each subsector over the period

2021 – 2040 differ to the assumed growth rates presented in Table 15 because of projected new entrants into the market, as described in Table 15.

6.3.4 Table 16 shows the projected turnover and GVA per annum, and FTE supported in 2040 for each product group (that can be displayed) under the BAU and the Higher Growth scenarios. The figure shows that the impacts under the Higher Growth scenario are expected to be the more noticeable in the longer term, relative to the BAU scenario. Moreover, the largest impacts are expected to be in relation to All Other Products, i.e. animal food, horticulture and biorefining (biorefining only in the higher growth scenario).

Table 16 Projected turnover (£m per annum) in 2021 and 2040 under the BAU and higher growth scenarios

Product group	2021		2040	
	BAU	HG	BAU	HG
Food	2.0	2.1	6.0	15.6
Bioactives	0.7	0.7	3.5	16.1
All other products	2.5	2.5	6.4	22.6
Total (all products)	5.2	5.3	15.9	54.3
All other' represents animal feed and horticulture under the BAU scenario; and animal feed, horticulture and biotechnology/ innovative products under the high growth scenario				

7 Potential economic impact on supply chains under the projected future scenarios

7.1 Overview

7.1.1 This section provides an analysis of the economic impacts on the seaweed-based industry (direct impacts), and its supply chain (indirect effects). Thus, the impacts on seaweed harvesting and production businesses, and the impacts on the associated upstream and downstream supply chain companies are incorporated under the different scenarios (BAU and higher growth projected future scenarios) described in Section 6.

7.1.2 Whilst the complete methodology used to estimate turnover impacts for the seaweed industry and its supply chain is set out in Appendix F (Sections F.2 and F.3), a brief summary is presented here. Under both scenarios (presented in Section 6), projected turnover for the industry has been estimated up to the year 2040. Output multipliers have been used to estimate direct and indirect output for the industry and its supply chain. Furthermore, the breakdown of supply chain benefits has been estimated. Specifically, the multipliers capture:

- **Direct effects:** When there is an increase in final demand for a product, the equivalent increase in turnover is referred to as the direct effect;
- **Indirect effects:** To meet the increase in demand for final products, firms will need resources and services from their supply chains, the increase in turnover for firms along the supply chain is referred to as the indirect effect; and
- **Total effects:** represents the total impact on the industry and comprises both direct and indirect effects.

7.1.3 This section presents the results of applying output multipliers to projected turnover under both scenarios. Whilst many firms are vertically integrated businesses, the analysis has separated businesses who produce seaweed (i.e harvesting and cultivation) and businesses who produce seaweed-based

products (e.g. human food products). The separation enables the estimation of benefits along the whole supply chain. In practice, many of these firms are one and the same and as such various steps have been undertaken to avoid double counting, for more detail see Appendix F (Sections F.2 and F.3).

7.2 Direct and indirect benefits: turnover

Seaweed production

Under the BAU scenario:

- Total turnover for seaweed production and its supply chain is estimated to increase from £1.1 million in 2021 to £3.4 million in 2040. This is comprised of wild seaweed harvesting with turnover from seaweed producers (direct effect) increasing from £930,000 in 2021 to £2.9 million in 2040; and businesses in the supply chain increasing turnover from £160,000 in 2021 to £500,000 in 2040 (indirect effect).

Under the Higher Growth scenario:

- Total turnover for seaweed production and its supply chain is expected to increase from £1.1 million in 2021 to £8.1 million in 2040. This is comprised of both wild seaweed harvesting and cultivation. For wild harvesting, production turnover is expected to increase from £930,000 in 2021 to £3.5 million in 2040 (direct effect); whilst supply chain turnover is expected to increase from £160,000 in 2021 to £590,000 in 2040 (indirect effect). For cultivation, turnover is expected to increase from £0 in 2021 to £2.8 million in 2040; whilst supply chain turnover is expected to increase from £0 in 2021 to £1.2 million in 2040.

7.2.1 Table 17 summarises the results under both scenarios for 2040. Detailed, year by year estimates are provided in Appendix G.

Table 17 Summary of turnover estimates from seaweed production under both scenarios

Production type	Effect	2040	
		BAU	Higher growth
Harvesting	Direct effect	£2.9 million	£3.5 million
	Indirect effect	£0.5 million	£0.59 million
Cultivation	Direct effect	N/A	£2.8 million
	Indirect effect	N/A	£1.2 million
Total		£3.4 million	£8.1 million
Rounding may lead to figures not summing exactly in some cases.			

7.2.2 Figure 6 summarises the calculation for seaweed production for the BAU and Higher Growth scenarios.

7.2.3 The flowchart sets out the steps in the calculation as well as the assumptions made. The assumptions are coded using a RAG (red-amber-green) system to indicate the degree of uncertainty introduced into the calculations (red=high; amber=moderate; green=low). It is important to remember that the calculations are based on scenarios, which are projections into the future so will have a high degree of uncertainty at most points during the calculation.

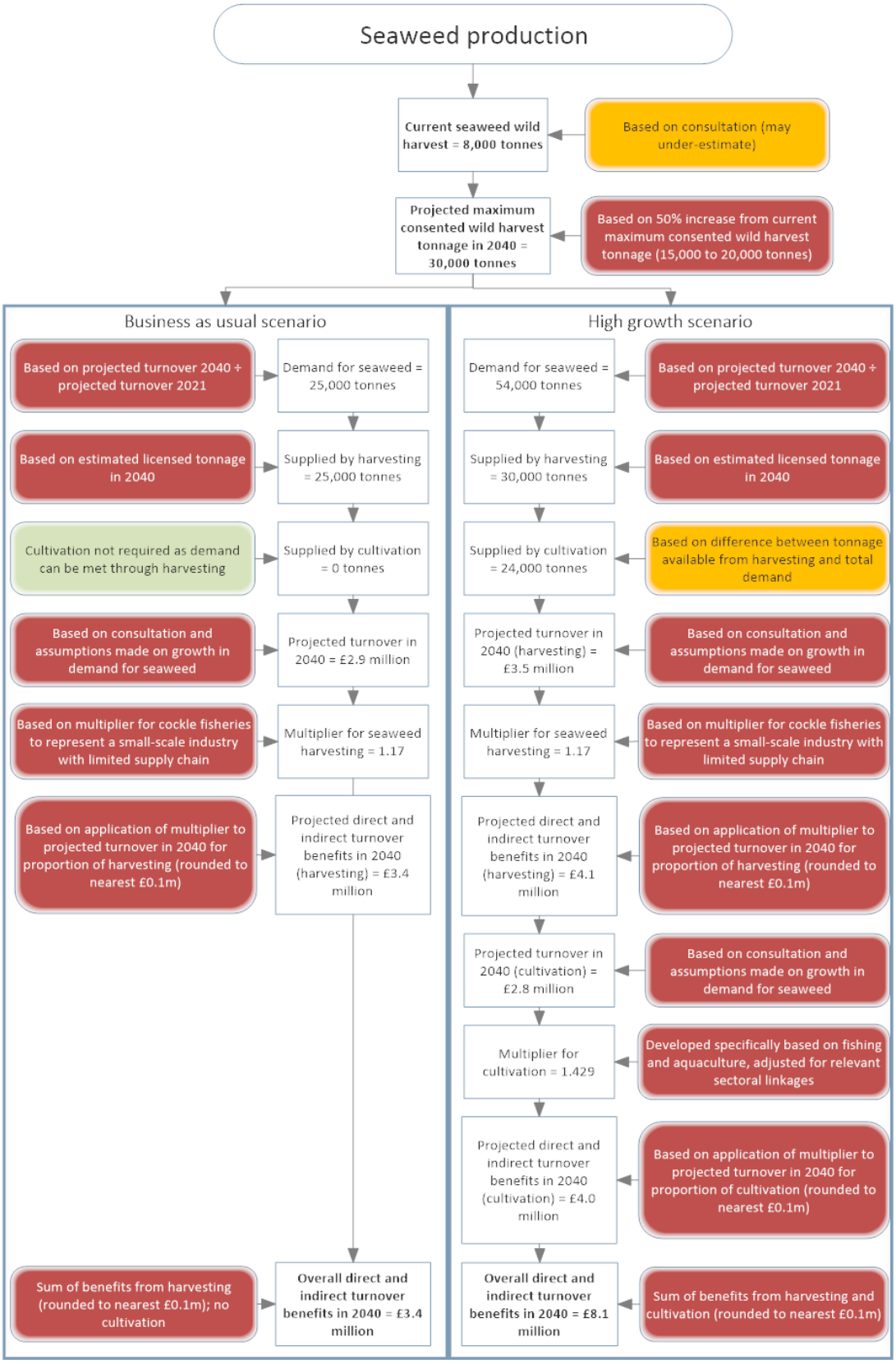

Figure 6. Approach to estimating direct and indirect turnover benefits for seaweed production

Seaweed-based products

7.2.4 Seaweed-based products have been divided into three main categories: human food, bio-actives (cosmetics, pharmaceuticals and nutraceuticals) and all other products (animal food, horticulture and biorefining (the latter in the higher growth scenario only)). The results presented here summarise the impacts on turnover across all of the product ranges and their supply chains.

7.2.5 It should be noted that determining the link between the value of seaweed production in 2040 (wild harvesting and cultivation) and the value of seaweed-based products in 2040, in terms of which products will use wild harvested or cultivated seaweed, was not possible in this study. This is due to the uncertainty regarding the proportion of wild harvested vs cultivated seaweed that operational business would choose to incorporate into their products in 2040, which in turn would depend on other factors, for example, the cost of cultivated seaweed in 2040 and the structure of the industry in 2040 (e.g. whether companies are vertically integrated and use their own wild harvested or cultivated seaweed for in-house production of seaweed-based products).

Under the BAU scenario:

- Total turnover from seaweed-based products and the supply chain is expected to increase from £6 million in 2021 to £18.7 million in 2040. This is comprised of turnover for business who produce seaweed-based products increasing turnover from £4.9 million in 2021 to £15.4 million in 2040; with supply chain business are estimated to increase turnover from £1.1 million in 2021 to £3.3 million in 2040. By type of product, turnover in 2040 is:
- Human food: £5.82 million for producers of human food products and £1.66 million for supply chain businesses in 2040
- Bio-actives: £3.41 million for producers of bio-actives and £0.26 million for supply chain businesses in 2040
- All other products: £6.16 million for producers of animal food and horticulture and £1.4 million for supply chain businesses in 2040

Under the higher growth scenario:

- Total turnover from seaweed-based products and the supply chain is expected to increase from £6.2 million in 2021 to £63.1 million in 2040. This is comprised of turnover for business who produce seaweed-based products increasing turnover from £5 million in 2021 to £52.6 million in 2040; with supply chain business are estimated to increase turnover from £1.2 million in 2021 to £10.5 million in 2040. By type of product, turnover in 2040 is:
- **Human food**: £15.2 million for producers of human food products and £4.33 million for supply chain businesses in 2040
- **Bio-actives**: £15.6 million for producers of bio-actives and £1.17 million for supply chain businesses in 2040
- **All other products**: £21.9 million for producers of animal food, horticulture and biorefining and £4.97 million for supply chain businesses in 2040.

7.2.6 Table 18 summarises the findings under both scenarios for the year 2040. Year by year estimations can be found in the technical annex.

7.2.7 Figure 7 summarises the calculation for seaweed products, covering human food, with Figure 8 covering bio-actives and Figure 9 summarising the calculations for all other products (animal food, horticulture and biorefining (the latter in the higher growth scenario only)).

Table 18 Turnover (£m) in 2040 from seaweed-based products under both scenarios

Production type	Effect	Turnover in 2040 (£ million)	
		BAU	Higher Growth
Food	Direct effect	£5.82	£15.2
	Indirect effect	£1.66	£4.33
Bio-actives	Direct effect	£3.41	£15.6
	Indirect effect	£0.26	£1.17
All other products	Direct effect	£6.16	£21.9
	Indirect effect	£1.4	£4.97
Total	Total direct effect (across all products)	£15.4	£52.6
	Total indirect effect on supply chain businesses (across all products)	£3.3	£10.5
	Total (Direct and indirect)	£18.7	£63.1
Rounding may lead to figures not summing exactly in some cases.			

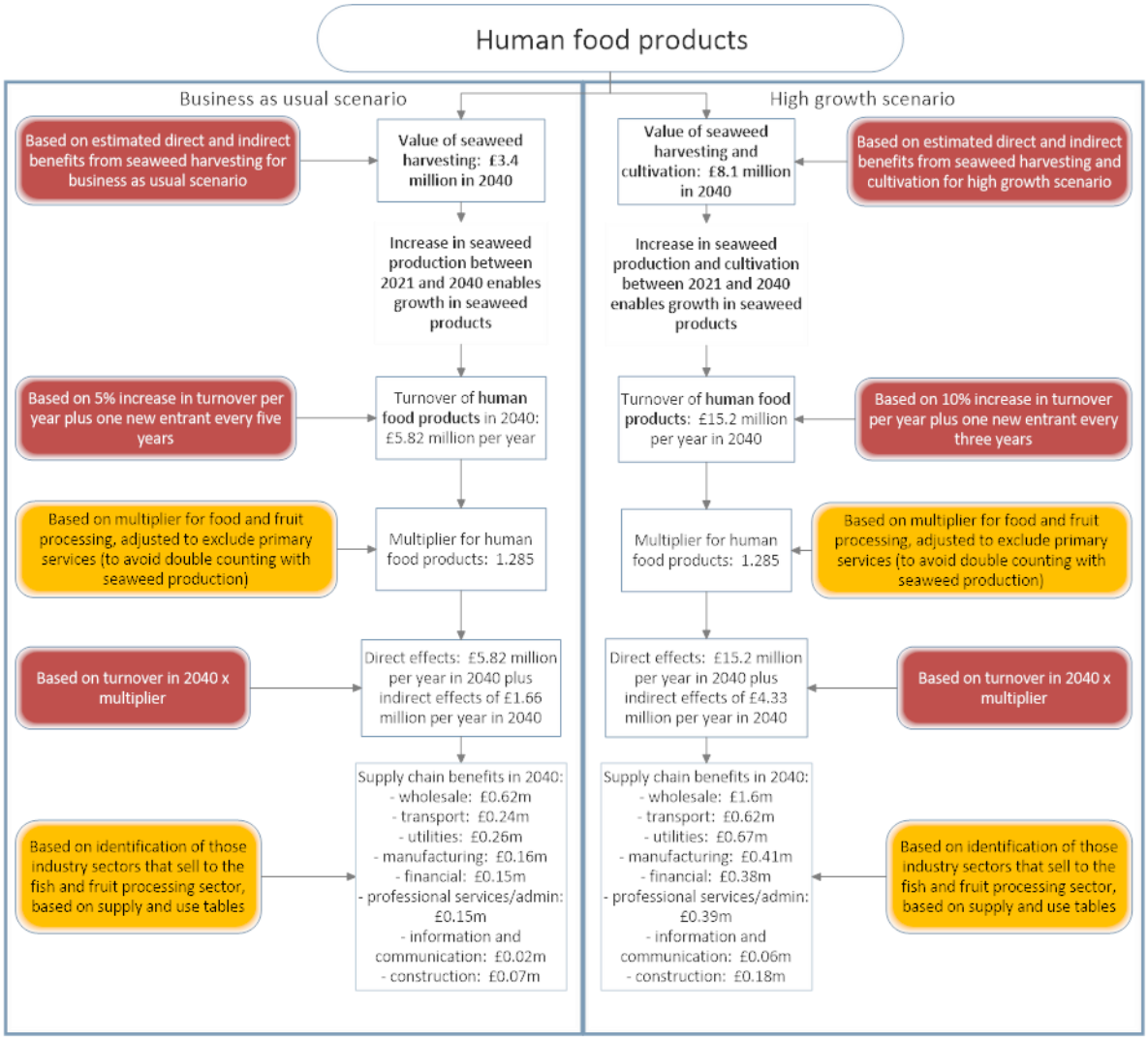

Figure 7. Approach to estimating direct and indirect turnover benefits for seaweed products: human food

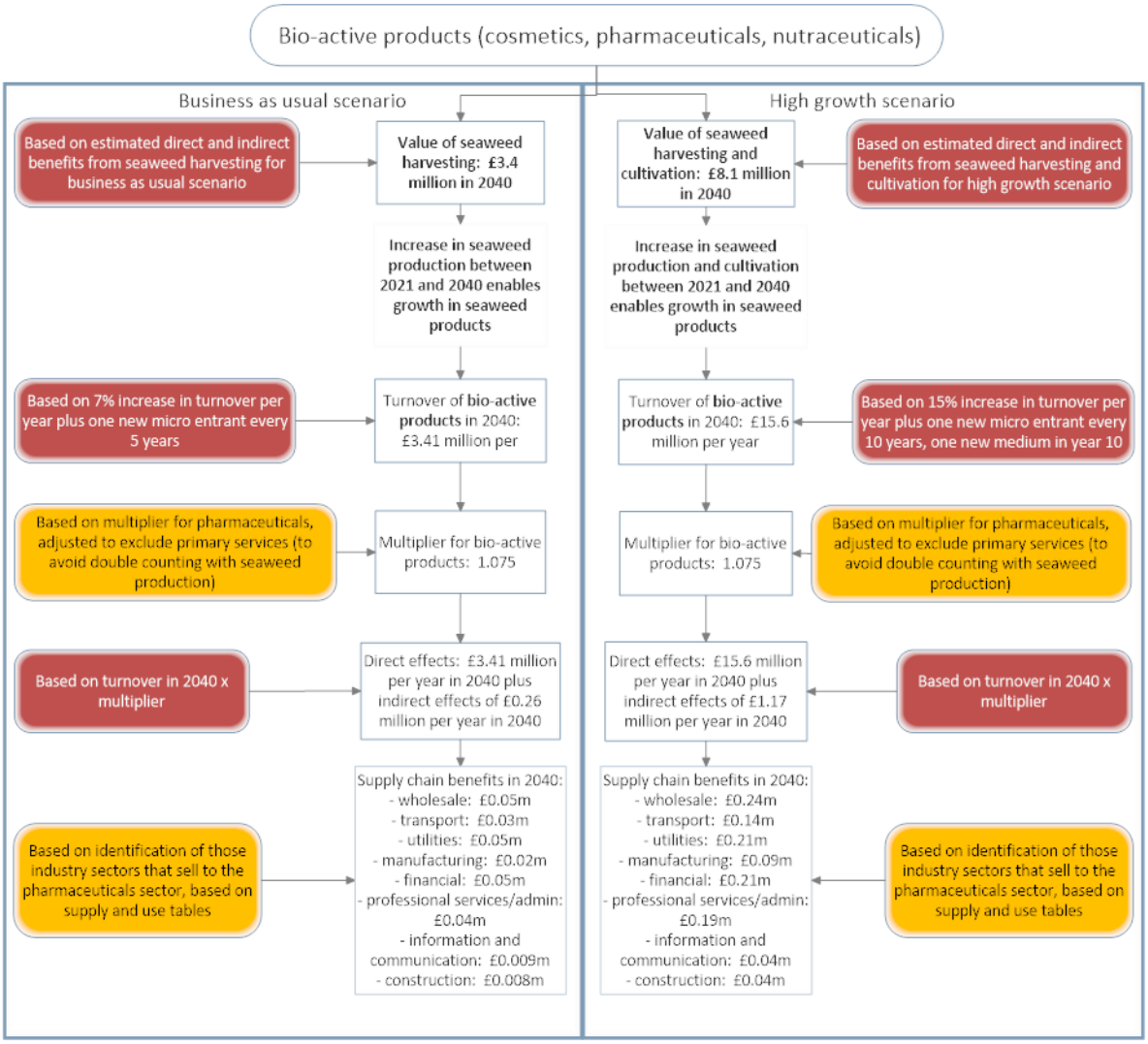

Figure 8. Approach to estimating direct and indirect turnover benefits for seaweed products: bio-actives

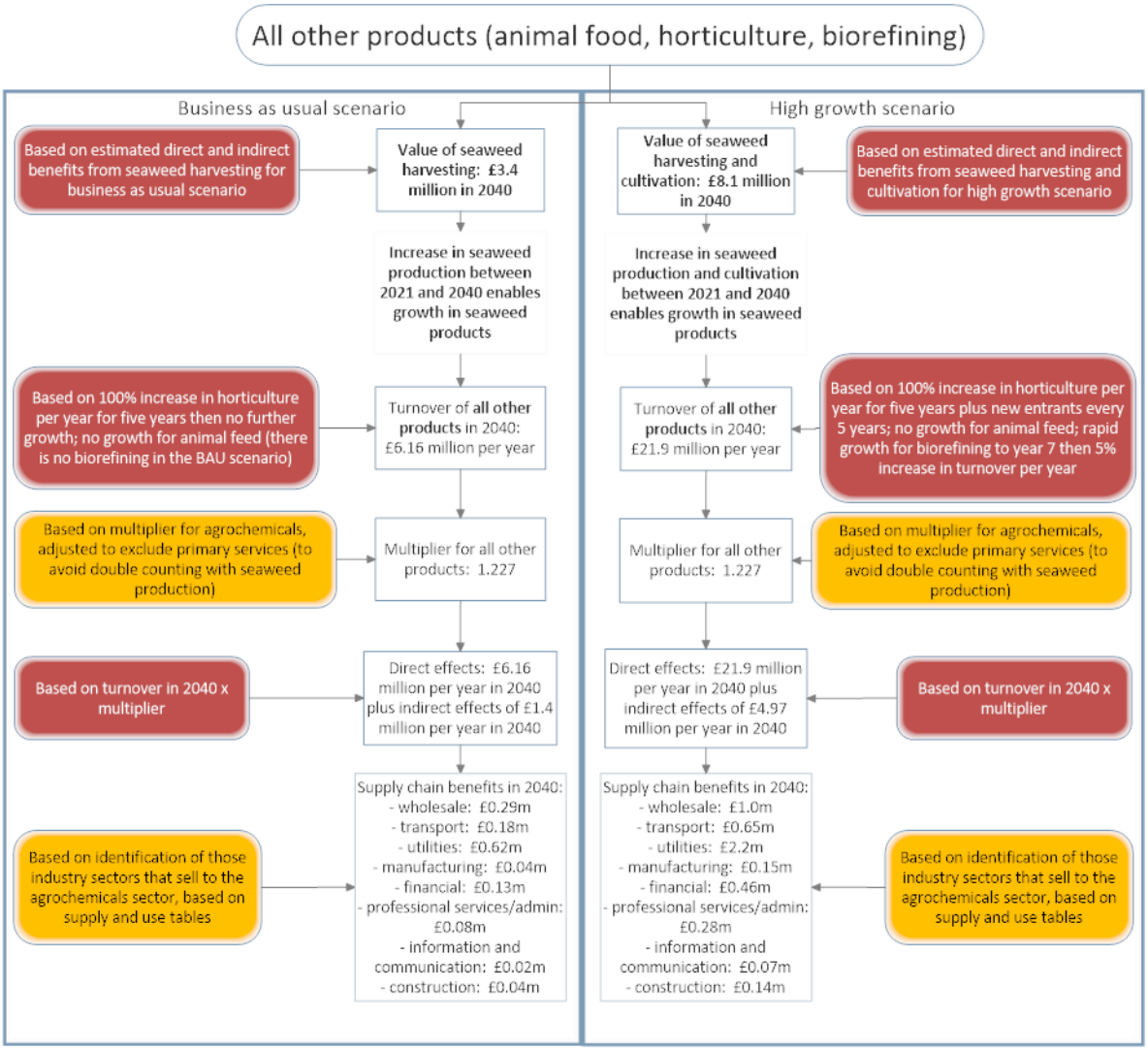

Figure 9. Approach to estimating direct and indirect turnover benefits for seaweed products: all other products (animal food, horticulture, biorefining)

8 Wider socio-economic impacts under the projected future scenarios

8.1 Overview

8.1.1 This section presents the findings of the wider socio-economic impacts that could arise as a result of the development of the industry, under the different scenarios. The socio-economic impacts are presented in four subsections: GVA impacts, employment impacts, regional impacts and social impacts. It includes both the direct and indirect effects on the economy as well as any other wider effects on the economy

8.1.2 Whilst the complete methodology employed to undertake this socio-economic assessment is set out in Appendix F (Sections F.4 and F.5), a brief summary is presented here. Under both scenarios, projected turnover for the industry has been developed up to the year 2040. GVA effect and employment effect multipliers have been used to estimate the GVA value of the seaweed industry and its supply chain to the Scottish economy and the maximum number of FTE supported by the industry. Specifically, the multipliers capture the following:

- GVA effect multipliers estimate the value of goods and services to the economy from the seaweed industry and its supply chain (Type 1: direct and indirect effects) and the spend by people employed directly and indirectly in the seaweed industry and its supply chain on local goods and services (Type 2: Induced effects); and
- Employment effect multipliers estimate the number of FTE supported by the seaweed industry and its supply chain (Type 1: direct and indirect effects) and the number of FTE supported through the additional spending (Type 2: Induced).

8.1.3 The resulting estimates of GVA and FTE jobs have then been applied to projections of the Scottish economy to estimate the proportion of GVA that the

seaweed industry would represent and its likely impact on the number of unemployed people in Scotland.

8.1.4 Following this, two illustrative area-based scenarios have been developed to assess what the impacts could mean at a local level . This, on the one hand, illustrates the importance of choosing one location over another and, on the other, helps to assess the scale of impacts (both positive and negative) if the industry were to cluster within a community. In practice the degree of impacts presented within the case studies would depend on the extent to which the communities are able to realise these opportunities. Specifically, it has been assumed that industry concentration within each community is 25% (with the remaining 50% being evenly spread and located elsewhere in Scotland). This % concentration was selected as a potential threshold to consider both positive and negative impacts on a community (from this it follows that a smaller concentration may have a smaller effect that is difficult to detect).

8.1.5 The social impacts are assessed using social clusters, which are groupings of impacts intended to capture those effects that have been identified as being most significant to individuals and communities, and which align with national indicators and sustainable development goals from Scotland's National Performance Framework. The approach of assessing social impacts using social clusters has previously been used to assess the impacts of offshore renewables on Scottish communities[29]. Social impacts are described, and a rating has been assigned to enable comparison of the expected magnitude of impacts. The ratings range from (as shown in Table 19):

[29] Collingwood Environmental Planning Ltd et al. 2016. A two way conversation with the people of Scotland on the social impact of offshore renewables, Final Dialogue Report; as reported by Marine Scotland (2018): Sectoral Marine Plan for Offshore Wind Energy (encompassing Deep Water Plan Options) Social and Economic Impact Assessment Scoping Report.

- Major negative (- - - -), which is associated with impacts that are expected to have a noticeable effect that is sufficient to cause complaints or protests from the community through to
- Major positive (+ + + +), which is defined as having a noticeable effect that supports new services or activities within the community.

Table 19 Ratings for use in the socio-economic impact assessment

Negative impacts (-)	Positive impacts (+)
Major (- - - -): sufficient negative impacts predicted to have a noticeable effect that is sufficient to cause complaints and/or protests from the community	Major (+ + + +): sufficient positive impacts predicted to have a noticeable effect that is sufficient to enable new services or activities within the community
Moderate (- - -): sufficient negative impacts predicted that result in concerns being raised by the community	Moderate (+ + +): sufficient positive impacts predicted that result in increased levels or expansion of existing activities or services
Minor (- -): negative impacts predicted that may be noticed but which are accepted by the majority of the community	Minor (+ +): positive impacts predicted that may be noticed but which support existing services or activities but not the extent that they can expand
Negligible (-): small negative impacts that are unlikely to be noticed by the majority of the community	Negligible (+): small positive impacts that are unlikely to be noticed by the majority of the community
Neutral/no overall impact (0)	
Notes: Based on work undertaken by RPA with ABPmer for a series of socio-economic impact assessments undertaken for Scottish Government and Marine Scotland.	

8.1.6 There is limited research on the potential social impacts of the seaweed-based industry within the UK (examples include Billing et al 2020 (social licence and seaweed farming) and Gegg and Wells, 2019 (public perception of macroalgae

for biofuel production))[30]. As such, the social impacts in this study are only considered at a relatively high level (based on the methodology described in Appendix F) and would benefit from further attention as the sector develops and/or a strategic plan for the sector is prepared. Furthermore, It should be noted that the social impacts presented in this section are not informed by stakeholder consultation, which was outwith the scope of this study.

8.2 GVA Impacts

8.2.1 This subsection sets out the projected economic impact of the Scottish seaweed industry, under both the BAU and higher growth scenario. The discussion covers both seaweed production and seaweed products, hereafter known as the 'Scottish seaweed industry'. For a more detailed explanation of the methodology, see Appendix F (Sections F.4 and F.5).

8.2.2 Overall, the Scottish seaweed industry is expected to contribute the following to the economy by 2040:

- Under the BAU scenario, the Scottish seaweed industry and its supply chain are expected to contribute £11.5 million in GVA to the economy by 2040. The increase in income for employees associated with the seaweed industry and its supply chain as a result of higher demand for seaweed, i.e. Type 2 effect, is expected to contribute a further £1.9 million to the economy by 2040. Overall, this means that the Scottish seaweed industry is expected to contribute £13.4 million per year to GVA in Scotland in

[30] Most research has been conducted in Asia (Gegg and Wells, 2019) where positive social impacts of cultivating this feedstock [raw material] have been noted, such as social equality through female employment and, because of increasing incomes, greater community cohesion and participation in leisure activities (Troell et al., 2006; Roesijadi et al., 2010; Hurtado, 2013; Kronen, 2013, all cited in Gegg and Wells (2019)). However, research has yet to focus on the societal impacts in the UK (Gegg and Wells (2019),

2040. For context, this could represent a total of 0.007% of Scotland's GVA[31].

- Under the higher growth scenario, the seaweed industry and its supply chain in Scotland is estimated to contribute £38.5 million to the Scottish economy by 2040. The subsequent spending from higher income for employees of the seaweed industry and its supply chain is estimated to contribute a further £6.6 million. Overall, this means that the Scottish seaweed industry is estimated to contribute £45.1 million per year to Scotland's economy in 2040, in terms of GVA. For context, this represents 0.025% of Scotland's estimated GVA in 2040[32]. By comparison, fishing and aquaculture represented £485 million, or 0.34% of total GVA in Scotland in 2018[33].

8.2.3 Table 20 summarises the results of the analysis. As it can be seen, the high growth scenario would contribute an additional £31.7 million per year to the Scottish economy.

[31] This is based on an illustrative estimation of Scottish GVA in 2040, based on current GVA projected into the future with an annual growth rate of 1.1%. See Table 6, Appendix F for data, assumptions and sources.

[32] This is based on an illustrative estimation of Scottish GVA in 2040, based on current GVA projected into the future with an annual growth rate of 1.1%. See Table 6, Appendix F for data,, assumptions and sources

[33] Office of National Statistics (2019) Regional gross value added (balanced) by industry. Table 1c: NUTS1 % UK current prices. Accessed at Regional gross value added (balanced) by industry: all NUTS level regions - Office for National Statistics

Table 20 Summary of GVA effects per year by 2040

Impact	BAU scenario	Higher growth scenario
Type 1 GVA effect	£11.5 million	£38.5 million
Type 2 GVA effect	£1.9 million	£6.6 million
Total GVA effect	£13.4 million	£45.1 million
Rounding may lead to figures not summing exactly in some cases.		

8.3 Employment Impacts

8.3.1 This subsection sets out the projected employment impact of the Scottish seaweed industry, under both the BAU and the higher growth scenarios. It should be noted that employment impacts are given as the maximum number of FTEs in any one year. For a more detailed explanation of the methodology and the relevant assumptions, see Appendix F (Sections F.4 and F.5).

8.3.2 The level of skills required to fill these jobs may vary depending on the stage of the supply chain, for example with higher skills requirements for some processing jobs but fewer skill requirements for cultivation and harvesting. There is the potential for harvesting jobs to be seasonal too, which can benefit specific age groups, such as those in the younger age groups. There is also the possibility of in-migration to take up jobs, which may be more likely in island communities than mainland communities. Some illustrative case studies of social impacts on an island and mainland community are provided in Section 8.4 but should be treated as indicative only, as the exact impacts on the communities will depend on employment levels and skill-set of the baseline workforce.

8.3.3 Under the BAU scenario, it is expected that the number of jobs within the seaweed industry and its supply chain will grow from an estimated 40 FTE per year in 2021 to 130 FTE per year by 2040. Moreover, once the subsequent impacts of spending in the economy are taken into account, (Type 2 effect) it is estimated that a further 30 FTE jobs per year will be supported in the wider economy by 2040. As such, between 130 and 160 FTE jobs per year are expected to be supported by the seaweed industry in 2040. This could

represent a 0.14% decrease in the number of people unemployed in Scotland by 2040[34].

8.3.4 Under the high growth scenario, it is expected that the number of jobs within the seaweed industry and its supply chain will grow from an estimated 40 FTE jobs per year in 2021 to 400 FTE jobs per year in 2040. Furthermore, once increased household income and ensuing spending within the economy is taken into account, it is estimated that a further 90 FTE jobs per year will be supported in the wider economy in 2040. Overall, a between 400 and 490 FTE jobs per year is expected to be supported through the seaweed industry by 2040. This could represent a decrease of 0.43% in the number of people unemployed in Scotland by 2040[35].

Table 21 Summary of employment effects per year by 2040

Impact	BAU scenario	Higher growth scenario
Type 1 employment effect	130 FTE	400 FTE
Type 2 employment effect	30 FTE	90 FTE
Total employment effect	160 FTE	490 FTE
Rounding may lead to figures not summing exactly in some cases.		

8.4 Regional impacts: two illustrative examples

8.4.1 The impacts from the scenarios will have different implications depending on where the industry is located. Although at national level, the impacts are

[34] This is based on an illustrative estimation of unemployment in 2040. It is based on population projections whilst assuming the unemployment rate remains at 4.1% (2019 level). See Table F6 for data, assumptions and sources.

[35] This is based on an illustrative estimation of unemployment in 2040. It is based on population projections whilst assuming the unemployment rate remains at 4.1% (2019 level). See Table F6 for data, assumptions and sources

expected to be small or moderate at most, local impacts could be significant should activity be located in smaller rural communities.

8.4.2 This subsection presents the results of two illustrative case studies, based on an island community and a mainland community, with different baseline population and employment levels. These case studies are intended to provide insight into the potential impacts on representative communities within Scotland and are modelled on real locations but should not be interpreted as potential sites for industry location in the future. The two communities that have been developed are distinct in their characteristics in terms of population, location, employment, size of economy and community.

8.4.3 For the purpose of estimating impacts, it has been assumed that jobs are fully retained within the community. Naturally, the degree to which a given community would benefit from the seaweed industry would depend on the concentration of industry within that community and the extent to which jobs are retained locally. Moreover, it has been assumed for the purpose of estimation, that jobs are taken up by local people and no displacement occurs (in other words, new jobs are filled in by the unemployed). However, the extent of impacts may differ in reality depending on whether migration is required to fulfil the jobs created by the industry. It should be noted, social costs and benefits associated with migration for seaweed-based jobs are outlined in the social impact Section 8.5.

8.4.4 Case study A: Impact from seaweed industry in small Island community

This case study illustrates a small community (over 23,000 people) over a large geographical area. There is a high proportion of self-employed and micro-enterprises are common. The share of the population by age group is larger for the over 65s than the national average and gross weekly earning lower than the national average. The unemployment rate is 3% and nearly half of the population are economically active.

Under the Business as Usual Scenario, and assuming 25% of the seaweed industry develops within the community, it is estimated that GVA will increase

by around 0.5% by 2040. There will be reduced unemployment, with a decrease of around 12%.

The Higher Growth Scenario will have more significant impacts, with an estimated reduction of 36% in the number of people unemployed. Most of these impacts will be direct and indirect impacts (Type 1 multiplier effects36). The GVA could be expected to grow by 1.6% from its projected £690 million in 2040 (this compares well against the estimated 0.5% increase estimated under the BAU scenario).

8.4.5 Case study B: Impact from seaweed industry in a mainland community

This case study illustrates a bigger mainland community of 74,000 where the number of people active are 34,000 and the unemployment rate is 5%. The local GVA is £1.7 bn. This is still a rural community, but there is a smaller proportion of self-employed and micro-enterprises, with some large enterprises. The average weekly earnings are higher than in case study A but still below those in the cities.

Under the Business as Usual Scenario, and assuming again that 25% of the industry concentrates within the community, it is estimated that GVA will increase by around 0.2% by 2040. There will be reduced unemployment, with a decrease of around 3% by 2040.

The Higher Growth Scenario will have moderate impacts, with a reduction of 8% in the number of people unemployed. GVA is estimated to grow by 0.7%. Due to the larger size of the community in case study B compared to case study A, the impacts are expected to be less noticeable at a community level.

[36] Type 1 impacts represent impacts directly from the seaweed industry and its supply chain and type 2 impacts represent impacts from induced spending. GVA impacts are the estimated percentage increase in the communities GVA. Unemployment impacts represent the estimated percentage change to the number of people unemployed.

8.4.6 The case studies indicate that the impacts on both communities differ by a significant degree, and impacts are more significant in the island community than in the mainland community, with significant reduction in unemployment rate under the higher growth scenario. This shows how location may be a key aspect to consider and how the industry can be beneficial to specific communities when the priorities are to boost employment in a particular local area. Thus, although at national level, the seaweed industry may currently have a limited contribution to the national economy, it can be a driver of economic prosperity in more rural and deprived communities in the future, as modelled under the high growth scenario in 2040 for Case Study A[37]. This of course depends on the communities capacity to actually realise this opportunity.

8.5 Social impacts on individuals, communities and society: a national perspective

8.5.1 The social impacts consider impacts at three cluster levels: individuals, community and wider political and environmental impacts. It is important to note that this is a high level exploration of social impacts which may arise from the projected future scenarios. As the sector expands and develops, stakeholder and community opinion will be captured through consenting processes (e.g. marine licence applications for seaweed farms) and research into social licence and acceptance of seaweed cultivation (e.g. Billing et al, 2020). There are different aspects that are considered under each cluster, as depicted in Table 22; but not all of them will be relevant. For instance, it is unlikely that the development of a seaweed industry will have a significant impact on education and impacts on recreation and amenity will be highly dependent on location and conditions attached to consents. Equally, impacts on landscape will be highly

[37] This is consistent with wider stakeholder opinion expressed during the consultation regarding the importance of the current wild harvesting sector with regard to employment in remote coastal locations.

variable and likely to be part of the key considerations in the consenting processes.

Table 22 Social impact assessment

Cluster	Aspects included in the assessment	Assessment at the national and community scale	
		BAU scenario (2040)	**Higher Growth scenario (2040)**
Individual	Family, family life, inter-generational issues	Increase in employment with potential positive impacts on family life arising from increased financial stability, higher disposable income, reduction in child material deprivation Potential for negative impacts on family life if jobs require relocation which could have negative impacts on child wellbeing, or if increased working hours results in less family time Impacts significantly more noticeable at the local community level than on the national level	
		Increase of 160 FTE per year by 2040 nationally and 40 FTE per year by 2040 per community	Increase of 490 FTE per year by 2040 nationally and 122 FTE per year by 2040 per community
		National: + Island: + + Mainland: + +	National: + Island: + + + Mainland: + +
	Jobs, career, employment	Potential increase in the number of households with at least one member in paid employment, potential for on-the-job training improving skills and furthering career prospects. Potential for increased demand within existing supply chains, benefitting small business with increased financial security.	

Cluster	Aspects included in the assessment	Assessment at the national and community scale	
		BAU scenario (2040)	**Higher Growth scenario (2040)**
		Potential negative impacts to supply chain if there is a lack of spare capacity, but given the moderate nature of impacts, this effect is expected to be negligible	
		Reduction in unemployment of up to 12% (island), 3% (mainland) and 0.14% nationally	Reduction in unemployment of up to 36% (island), 8% (mainland) and 0.43% nationally
		National: + Island: + + Mainland: + +	National: + Island: + + + Mainland: + +
	Money, cost of living	Increased employment potentially increasing household net income, reducing the proportion spent on essentials (e.g. housing, food). Potential positive impacts on the proportion of individuals earning a living wage, particularly if skilled jobs are taken up by skilled individuals who were previously employed in unskilled jobs Potential negative impacts if jobs are filled from relocation, increasing prices and housing costs as demand rises, although likely to be highly negligible	
		Increase in GVA of £13.4 million per year by 2040 nationally, and increase of 0.5% (island) and 0.2% (mainland) GVA by 2040	Increase in GVA of £45.1 million per year by 2040 nationally, and increase of 1.6% (island) and 0.7% (mainland) GVA by 2040
		National: + Island: + Mainland: +	National: + Island: + + Mainland: +

[1] ...he potential scale for seaweed-based industries in Scotland:

Cluster	Aspects included in the assessment	Assessment at the national and community scale	
		BAU scenario (2040)	**Higher Growth scenario (2040)**
Community	Local jobs, local industry, community, sustainability	Potential increase in the number of innovative seaweed businesses, developing sustainable high value products Impacts on industry at the regional level could provide further support for businesses within a region, boosting the long-term sustainability of supply chain business. In particular, if supply chain efforts are coordinated with other similar industries. There could be some displacement from other industries, but due to the scale of growth considered here, it is expected that these will be negligible in the medium to long-term, where low skilled jobs could be filled in by people in current unemployment.	
		Some opportunities for diversification but limited to production since all seaweed is provided through wild harvesting	Potential for diversification of existing businesses, e.g. through increased demand for boats, ropes from growth of seaweed cultivation
		National: + Island: + Mainland: +	National: + Island: + + Mainland: + +
	Transport connections, technology connections	Unlikely to significantly impact on transport connections at the national level Minor potential for some improvements in existing transport connections if regional concentration of industry is particularly high, or negative impacts if regional concentration is particularly high without equivalent improvements to existing transport channels	

Cluster	Aspects included in the assessment	Assessment at the national and community scale	
		BAU scenario (2040)	**Higher Growth scenario (2040)**
		National: 0 Island: + Mainland: +	National: 0 Island: + Mainland: +
	Education	Potential increases to on-the-job training, investment into research and development. Impact negligible at the national level, but could have significant impacts at a regional level if industry concentration is sufficiently high If jobs require relocation, potential for negative impacts from increased pressure on schools, potentially increasing class sizes. Likely to be negligible at a national level, but impacts may be more pronounced at a local level. There may be positive impacts where additional families could help support local schools that are below capacity	
		Likely to be limited in-migration to take up jobs, could be more significant for island community than mainland.	In-migration to take up skilled jobs more likely in island community with impacts dependent on age of migrants and whether they bring their family and settle for the longer-term
		National: - / + Island: - / + Mainland: - / +	National: - / + Island: - / + Mainland: - / +
	Shops, housing	Disposable income after housing costs may benefit local business and shops, unlikely to increase the number of shops but could provide existing support to established businesses Potential negative effect on housing availability, but unlikely to be noticeable at the national level.	

[1] ...he potential scale for seaweed-based industries in Scotland:

Cluster	Aspects included in the assessment	Assessment at the national and community scale	
		BAU scenario (2040)	**Higher Growth scenario (2040)**
		Potentially noticeable at the regional level if relocation for jobs is particularly high	
		Likely to be limited in-migration to take up jobs, so impacts on housing demand and prices is expected to be limited	In-migration to take up skilled jobs more likely in island community with need for housing that could increase de-mand
		National: - Island: - Mainland: -	National: - Island: - - Mainland: -
	Socialising, recreation, parks, leisure	Potential increase in free time for socialising and recreation if jobs are retained locally, potential negative impacts on free time for socialising if jobs require extended commuting. There could be some relocation to rural areas, depending on location of development. There could be some negative impacts on landscape and amenity, hindering recreation. The net effects will depend on scale of development, management practices and location so they are difficult to establish with accuracy.	
		National: - / + Island: - / + Mainland: - / +	National: - / + Island: - / + Mainland: - / +
	Friends, being involved, supporting others	Increased employment leading to a decrease in relative poverty may improve the proportion of individuals who feel supported Increased employment potentially increasing individuals social network, providing more support and opportunity to engage in social activities	

[1] ...he potential scale for seaweed-based industries in Scotland:

Cluster	Aspects included in the assessment	Assessment at the national and community scale	
		BAU scenario (2040)	**Higher Growth scenario (2040)**
		Potentially positive impacts from increased employment reducing social exclusion	
		National: + Island: + Mainland: +	National: + Island: + + Mainland: +
	Local identity, cultural heritage, Gaelic	Potentially positive impacts from increased employment if increased income leads to more engagement with cultural activities Impacts on local identify depend on the extent to which jobs are retained by local people or relocation is required. May impact on proportion of Gaelic speakers if relocation takes place, which could have positive or negative impacts on local identify Local industry conducive to strong community identity at the local level, sense of pride to region	
		National: + Island: + Mainland: +	National: + Island: - / + Mainland: +
	Healthcare	Potential positive impacts on both physical and mental health. Employment highly correlated with improvements to healthy life expectancy, and reduced mental health conditions such as depression and anxiety If relocation is required, potential for increased demand on healthcare providers, although likely to be negligible.	
		National: + Island: + Mainland: +	National: + Island: + + Mainland: +

[1] The potential scale for seaweed-based industries in Scotland:

Cluster	Aspects included in the assessment	Assessment at the national and community scale	
		BAU scenario (2040)	**Higher Growth scenario (2040)**
	Connection to nature, landscape	Potential positive impacts on connection with sea through career, positive impacts if relocation from urban to rural with more access to nature If jobs are retained locally positive impacts on commute times, improving opportunity to spend time in local natural environments Potential negative impacts on perception of local landscape if industry is highly developed	
		National: + Island: + Mainland: +	National: + Island: - / + + Mainland: - / +
	Local political and decision-making systems	Potential positive impacts on political engagement, with evidence suggesting unemployment correlates with political disengagement, particularly where unemployment drives social exclusion	
		National: + Island: + Mainland: +	National: + Island: + + Mainland: +
Wider political and environmental context	National and EU level political and decision-making systems	Potential positive impacts on Scotland's reputation within the seaweed industry which could potentially enable future investment or government funding schemes Potential positive impacts on political engagement and satisfaction with rising employment	
		National: + Island: + Mainland: +	National: + Island: + + Mainland: +
HG = Higher Growth			

ne potential scale for seaweed-based industries in Scotland:

8.6 Impact on other marine industries

Under the BAU scenario

8.6.1 Wild harvesting of seaweed has been undertaken in Scotland for hundreds of years and occurs in the intertidal or shallow subtidal area. Under the BAU scenario wild harvesting is projected to increase from approximately 8,000 tonnes p.a. to 25,000 tonnes p.a. by 2040.

8.6.2 The Wild Seaweed Harvesting Strategic Environmental Assessment (SEA) (Marine Scotland, 2016) identified a range of potential environmental effects associated with wild harvesting of kelps, including loss of habitat, loss of nursery grounds for juvenile fish and invertebrates, physical effects at the coast and/or loss or damage to cultural heritage assets. Assessment of environmental impacts (of wild harvesting or cultivation of seaweed) was outwith the scope of this current study, however, some of the potential environmental effects described in the SEA could have potential consequences (directly or indirectly) for other marine users, including commercial fishing and recreation and tourism, as well as coastal communities. In this study, consultation indicated that many industry stakeholders felt that sector growth (in the form of expansion of production of existing seaweed-based products and development of new products) could be met by raw material provided through wild harvesting (Section 5). The current scale of wild harvesting is a very small proportion of the available resource[38] and no major environmental issues have been identified in relation to the current levels of harvesting currently undertaken. However, no 'threshold level' of kelp harvesting was identified in Burrows et al (2018) or the SEA that could be deemed to represent an

[38] Burrows et al (2018) predicted a total biomass of 20 Mt for *L. hyperborea*, 2.5 Mt for *Saccharina latissima*, 188000t (0.19Mt) for *Saccorhiza polyschides* and 161000t (0.16Mt) for *Laminaria digitata* around the Scottish coast. It should be noted that no estimate of biomass for Ascophyllum nodosum (the species wild harvested in the largest quantities in Scotland) were made.

‘insignificant’ impact. Hence, the potential environmental effects of increasing wild seaweed harvesting to 25,000 tonnes (noting the vast majority of which under the BAU scenario would still be the wrack species *A. nodosum*), would need to be assessed under the current consenting process (see Appendix A). Direct effects (e.g. competition for sea space) or indirect effects (arising from any environmental impacts) would also need to be assessed.

Under the higher growth scenario

8.6.3 Under the higher growth scenario, wild harvesting is projected to increase to 30,000 tonnes p.a. slightly greater than under BAU. As per the BAU scenario, the potential environmental impact of increasing wild harvesting levels would need to be assessed under the current consenting process. Direct effects (e.g. competition for sea space) or indirect effects (arising from any environmental impacts) would also need to be assessed.

8.6.4 The Higher Growth scenario assumes production of 24,000 tonnes of cultivated seaweed. This level of cultivation would require significant infrastructure (i.e. farm developments at sea) and hence may present potentially significant interactions with some other marine industries, in particular the commercial fisheries sector, depending on the extent and location of the developments. Furthermore, as in general competition for ‘sea area’ is a constraint on both emerging and established marine sectors looking to expand the seaweed cultivation sector may compete with finfish and shellfish aquaculture business for lease areas.

8.6.5 The spatial extent of seaweed farms that might be required to provide an annual harvest of 24,000 tonnes will depend on the density of seaweed within the farms (i.e. whether intensive or extensive farming is undertaken). Based on information contained within a scoping report for an offshore seaweed farm off the Norfolk coast (Sustainable Seaweed Limited, 2019), this would require production over an area of several km^2 for brown seaweeds such as *S. latissima*. However, given the emergent nature of the cultivation sector in the UK, it is not possible to accurately estimate the area required to produce 24,000 tonnes per annum. It can be noted that in July 2021 the total area

licensed for seaweed farming in Scotland, together with the area contained within marine licence applications for seaweed farms, is over 2km^2 [39], with the largest licensed area to date being 0.5 km^2.

8.6.6 It is assumed that any seaweed farm would exclude the use of mobile fishing gear (resulting in the permanent loss of fishing grounds) although, there may be potential for the continued use of static gear (pots/creel) for example if the seaweed farm design enables access for fishing vessels to deploy and retrieve this gear. If the seaweed cultivation sector develops, liaison with static gear fishermen in areas of interest for farms regarding design and access will likely be needed to mitigate any negative interactions and impacts.

8.6.7 A further impact of potential seaweed farming related infrastructure deployment at sea may relate to perceived or real visual impacts of seaweed farms on the amenity value of an area, an issue which is also dealt with via the marine licensing system. To the best of our knowledge there is no evidence that aquaculture installations impact tourism (e.g. Nimmo et al 2011), however, depending on the level of social licence for seaweed farms within communities this may result in difficulty in finding socially acceptable locations.

8.6.8 Based on the above, it is likely that the emergence of a cultivated seaweed sector would have some interaction with commercial fishing activity and some level of competition with finfish and shellfish aquaculture for lease areas. The scale of any impacts on other marine users will depend on the nature, location and extent of cultivated seaweed installations which would be addressed through the marine licensing process for individual seaweed farm developments. Farms covering more than 1000 m^2 of the seabed are commonly required to undertake pre-application consultation under the Marine Licensing (Pre-application Consultation) (Scotland) Regulations 2013 (Marine Scotland Licensing Operations Team, *pers. comm.*).

[39] Data sourced from the Marine Scotland Marine Licence Application website: https://marine.gov.scot/marine-licence-applications [accessed 21.07.2021].

9 Conclusion

9.1.1 This study was commissioned to provide an evidence-based 'baseline' characterising the current seaweed-based industry in Scotland and to develop 'plausible' projected growth scenarios for the sector over the next 20 years (to 2040).

9.1.2 The outcomes of the study show that the current seaweed-based industry, which produces a range of products and ingredients for the food, animal feed, horticulture, cosmetic, nutrition and pharmaceutical sectors, is almost entirely dependent on wild harvested seaweed for raw material. Although the scale and economic impact[40] of the current sector (**total turnover c. £4 million; mean turnover £500,00; total GVA estimated at £510,000 per annum**) is small relative to other industry sectors (e.g. fishing) it was described as of vital importance to local communities with regard to provision of jobs and income. Many of the businesses surveyed in this study expressed an intention to expand production and their product ranges and had invested in the necessary equipment and infrastructure to do so. Nearly all felt that the raw material requirements for this expansion could continue to be met through harvesting of wild seaweed, although they were keen to incorporate farmed seaweed into their products if it was commercially viable to do so. Based on this information, one projected scenario (Business as Usual) was developed in which the industry growth continued to be based on the provision of raw material through wild harvesting, with the assumption that commercial scale cultivation did not develop sufficiently to provide any significant supply of farmed seaweed into the supply chain.

9.1.3 The other key message from stakeholders was the keen interest in developing the seaweed cultivation sub-sector in Scotland, to supply various existing and

[40] Based on eight companies for which data was available; hence likely to be an underestimate due to data gaps and not all companies identified and/or engaging with the project.

emerging markets. Some key constraints to this development were raised including the economic feasibility of farming seaweed, lack of access to investment and funding to set up farms and the lack of defined markets for the relatively low-value species which can currently be grown. However, there was also strong interest in developing a circular (zero waste) economy for seaweed in Scotland, for example through development of novel biotechnology to produce a range of products (with a range of values) from farmed seaweeds. Based on this information, a second projected scenario (the higher growth scenario) was developed in which industry growth was supported by the provision of both wild harvested and farmed seaweed, enabling more rapid expansion of the sector.

9.1.4 Under the **BAU scenario** the seaweed industry and its supply chain are estimated to:

- Generate a total turnover of £22.1 million per year by 2040, comprising:
  - £2.9 million for seaweed production and £500,000 for their supply chain;
  - £15.4 million for businesses who produce seaweed-based products and £3.3 million for their supply chain.
- Contribute £11.5 million in GVA per year by 2040 directly to the seaweed industry and indirectly to the supply chain and a further £1.9 million in GVA per year by 2040 once induced impacts are included.
- Directly and indirectly (via the supply chain) support 130 FTE per year by 2040, and a further 30 FTE per year once induced impacts are included.

9.1.5 Under the H**igher Growth scenario** the seaweed industry and its supply chain are estimated to:

- Generate a total turnover of £71.2 million per year by 2040, comprising:
  - £3.5 million for seaweed production (wild harvesting) and £590,000 for their supply chain;
  - £52.6 million for businesses who produce seaweed-based products and £10.5 million for their supply chain;

- £2.8 million for businesses who are cultivating seaweed and £1.2 million for their supply chain.

- **Contribute £38.5 million in GVA per year by 2040** directly to the seaweed industry and indirectly to the supply chain and a further and **a further £6.6 million per year in GVA once induced impacts are included**. Overall, this would mean total GVA of £45.1 million by 2040.
- Directly and indirectly (via the supply chain) support 400 FTE jobs by 2040 and a further 90 FTE once induced impacts are included.

9.1.6 An analysis of wider socio-economic impacts indicated that the impacts are likely to be positive with increased economic prosperity likely to have positive impacts on job opportunities, disposable income and the costs of living. There would also likely be positive knock-on effects for local businesses in the community; in particular, potential positive impacts are expected on the long-term sustainability of supply chains. However, there is potential for some temporary disruption if migration is required to fill some skilled jobs, potentially felt by the local population in addition to increased demand on essentials and services (e.g. schools, housing).

9.1.7 Overall, the socio-economic impacts at the local/regional level both in terms of GVA and employment are likely to be more significant, compared to the national level impact. Careful planning and location of seaweed industry could thus incentivise and help diversify local and regional economies to a greater degree, whilst making a substantial impact on the wellbeing of individuals, communities and wider industry at a local level. The positive impacts may be limited though depending on:

- The skill level needed with in-migration of skilled workers potentially limiting benefits to local communities;
- Whether production is undertaken in the same location as harvesting/cultivation where benefits could be limited to harvesting/cultivation, drying and transport if manufacture of products occurs elsewhere;

- Potential competition for resources, such as the seabed for cultivation or access to boats. However, the scale of development of the seaweed industry should make this less significant.

9.1.8 The potential impacts of the development of the seaweed sector on other marine users will be site specific. Expansion of the wild harvesting sector up to 25,000 (BAU) or 30,000 tonnes p.a. (Higher Growth) may have the potential to affect other users (for example, the most likely interaction is with commercial fishing activity (potting) should wild harvesting be extended within shallow subtidal areas). The environmental impact will need to be assessed under the current consenting process.

9.1.9 There is greater potential for the cultivated seaweed sector to interact with other marine users given the increasing competition for marine space. Potential interactions with other marine users include exclusion of commercial trawling activity (and possibly potting) within seaweed arrays as well as competition for space with finfish and shellfish aquaculture businesses. It is expected that such interactions would be managed through marine planning and marine licensing systems.

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11 Abbreviations

ABPmer	ABP Marine Environmental Research Ltd
BAU	Business As Usual
BIM	Bord Iascaigh Mhara
CBI	Confederation of British Industry
CES	Crown Estate Scotland
COVID	Coronavirus Disease
EU	European Union
EUR	Euro (€)
EUMOFA	European Market Observatory for Fisheries and Aquaculture
FAO	UN Fisheries and Agricultural Organisation
FOB	Free on Board
FTE	Full Time Equivalent
GDPR	General Data Protection Regulations
GVA	Gross Value Added
HG	Higher Growth
IBiolC	Industrial Biotechnology Innovation Centre
IMTA	Integrated Multi-Trophic Aquaculture
KCB	Knowledge Centre for Bioeconomy
NM	Nautical Mile
NRS	National Records of Scotland
NUTS	Nomenclature of Territorial Units for Statistics
ONS	Office for National Statistics
PSG	Project Steering Group
RAG	Red-Amber-Green
RPA	Risk and Policy Analysts
SAIC	Scottish Aquaculture Innovation Centre
SAMS	Scottish Association of Marine Science
SARF	Scottish Aquaculture Research Forum
SEA	Strategic Environmental Assessment
SME	Small to Medium Enterprise

SNH	Scottish Natural Heritage
SSIA	Scottish Seaweed Industry Association
UK	United Kingdom
USA	United States of America
USD	US Dollar ($)

12 Appendices

A Legislative and Regulatory Control of Wild Seaweed Harvesting and Seaweed Cultivation at Sea

A.1 Introduction

A.1.1 As noted in the main report, the future opportunities for the Scottish seaweed-based sector have been considered within the current legislative and regulatory framework with regard to wild seaweed harvesting and seaweed cultivation at sea. A detailed review of the current regulatory and legislative framework for wild harvesting and cultivation of seaweed has recently been undertaken by the Scottish Government's Seaweed Review Steering Group (2020). This appendix provides an overiew of the regulatory framework for wild seaweed harvesting and seaweed cultivation. All information is based upon the Seaweed Review Steering Group paper unless otherwise stated and for further detail, readers are directed to the full review.

A.2 Wild harvesting of seaweed

A.2.1 Wild harvesting of seaweed for commercial reward (i.e. not personal consumption) requires permission from the landowner (whether the CES, in which case a licence from CES is required, or a private landowner in which case permission is required) and potentially a marine licence depending on the method of harvesting. These requirements are described in more detail below.

Requirement for a Crown Estate Scotland Licence for wild harvesting of seaweed

A.2.2 The Crown is the owner of around half of the UK's foreshore and virtually all of the UK seabed out to the 12nm limit and in Scotland these assets are managed by Crown Estate Scotland (CES). Harvesting seaweed from the foreshore or seabed (i.e. below mean low water springs) managed by CES, for commercial

reward requires a licence to be obtained from CES[41]. A proportionate approach to the information required from the operator to obtain the licence is applied by CES. Depending on the intensity of harvesting (the volume to be harvested and the timescale for the harvesting), information requirements for the issue of a CES licence can include the following:

- A stock biomass assessment to predict sustainably available annual volumes for each species proposed to be harvested;
- A sustainable harvesting strategy; and
- A monitoring strategy setting out the data to be collected to inform the sustainability of the activity undertaken.

A.2.3 Further to NatureScot (formerly Scottish Natural Heritage, SNH) being satisfied by the information supplied by the applicant that the activity presents no evident risk of unacceptable environmental effects, a licence is issued, usually for a 3-5 year period. CES only applies species-specific harvesting volumes to operators undertaking larger-scale harvesting activities (i.e. generally harvest volumes of 100 tonnes per annum and above, depending on the intended time period over which harvesting would occur), based on the stock and sustainable harvest assessments supplied by the licensee during the licence application process. For smaller-scale operators, who require smaller volumes (for example, who may only require several hundred kilos of seaweed per annum), a maximum harvesting volume across all species collectively is applied in the licence (CES pers. comm.). The licence may be renewed subject to a review of the sustainability of the harvesting practice. The licence issued by the CES delineates the boundary of the harvesting area but does not grant exclusive rights to the seaweed resource in the area.

A.2.4 As noted above, collection or foraging of small quantitates of seaweed for personal use does not require a licence, although CES recommend that the

[41] Where the foreshore is owned by a landowner other than the Crown, the landowners permission is required

environmental sensitivities of collection from the wild are considered appropriately.

A.2.5 Of further relevance to wild seaweed harvesting, the Scottish Crown Estate Act, passed by the Scottish Parliament on 21 November 2018 (and which passed into law on 15 January 2019), includes a provision in Section 15 which will prevent the granting of rights (from CES) to remove wild kelp[42] from the seabed (bed and subsoil of the sea within the Scottish marine areas) if either subsection (2) or (3) applies:

(2) This subsection applies if—

- (a) removal of the kelp would inhibit the regrowth of the individual plant, and
- (b) the kelp removed is intended for commercial use.

(3) This subsection applies if—

- (a) removal of the wild kelp is a licensable marine activity, and
- (b) the Scottish Ministers have not granted a marine licence for that removal.

A.2.6 As such, this Act prevents the wild harvest of seaweed using any method which removes the whole kelp plant, such as those using toothed sledges, except in relation to the removal of kelp species for maintenance or other public interest reasons (e.g. removal of seaweed which has accumulated near cooling vents for power stations).

Requirement for a marine licence for wild harvesting of seaweed

A.2.7 Under the Marine (Scotland) Act 2010, Scottish Ministers are responsible for the marine licensing system and enforcement in the Scottish inshore region

[42] *L. hyperborea*, *L. digitata*, *S. latissima*, *Saccorhiza polyschides*, and *A. esculenta*

from 0-12 nautical miles (NM). The licensing regime allows regulation of the deposit and removal of substances and objects in the seas around Scotland and activities must take place in accordance with licence conditions.

A.2.8 Under Section 21 of the Marine (Scotland) Act 2020 the following is considered to be a licensable activity:

A.2.9 "To use a vehicle, vessel, aircraft, marine structure or floating container to remove any substance or object from the seabed within the Scottish marine area".

A.2.10 The implication for harvesting of wild seaweed is that the requirement to obtain a marine licence under the Marine (Scotland Act) 2010 is based on the method of harvest and not the volume taken. For example, neither gathering or harvesting seaweed by hand nor mechanical harvesting using specialised vessels or modified boats to cut floating seaweed stalks above the seabed are considered to be a licensable marine activity under the Marine (Scotland) Act 2010. This is because the seaweed (considered as 'a substance' within the context of the Marine Scotland Act 2010) is not being removed directly from the seabed[43]. In contrast, mechanical harvesting of seaweed using a method which removes the entire marine plant including the holdfast from the seabed (for example via by trawl, sledge or dredge), is considered a licensable marine activity under the Marine (Scotland) Act 2010.

A.3 Cultivation of seaweed

A.3.1 A number of consents are required to allow the establishment of an aquaculture installation for the cultivation of seaweed in the marine environment. The consenting process for marine aquaculture in Scotland, including the cultivation of seaweed, has been described in detail in Nimmo et al (2016) and SARF (2019). A summary of the consents required for seaweed cultivation is provided

[43] Anecdotal evidence suggests that this method may sometimes unintentionally pull up holdfasts or substrate – which could potentially be considered as "the removal of a substance or object from the seabed".

below based on these sources (for further detail readers are directed to these reviews).

- A marine licence under the Marine (Scotland) Act 2010 within 12 NM (or under the Marine and Coastal Access Act 2009 between 12-200 NM if offshore aquaculture develops in the future);
- A seabed lease from Crown Estate Scotland under the Scottish Crown Estate Act 2019; and
- A works licence under the Zetland County Council Act 1974 in Shetland only.

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B Seaweed Products and Uses

B.1 Overview of seaweed products and uses

B.1.1 This appendix provides an overview of the types of products obtained from seaweeds and the basis of the product groupings used within this study. For further information regarding the uses of seaweeds readers are directed to Cefas (2016) and Stanley et al. (2019).

B.1.2 Seaweeds can be used as a raw material for several end uses including human foods, animal feed, horticulture and fertiliser, hydrocolloids, bioactives used in the nutraceuticals, pharmaceuticals and cosmeceuticals industries, and biofuels (Stanley et al., 2019). There are also wider applications for seaweeds in bioremediation and integrated multi-trophic aquaculture (IMTA), as well as knowledge industries associated with the production of seaweeds and development of products.

Human food

B.1.3 Seaweeds can be used in a broad variety of formats (e.g. fresh, dried, powder or flakes, salted, canned, liquid extracts or as prepared foods) and used in human foods for direct human consumption (McHugh, 2003; Bixler & Porse, 2011; Anis et al., 2017). The use of seaweeds in foods and traditional cuisine is popular in Asian countries. The main types of seaweed used as food are *Laminaria* spp., *Undaria* spp., *Hizikia* spp., *Porphyra* spp. (nori or laver), *Palmaria palmata*, *Ulva* spp. and *Monostroma* spp. (Cefas, 2016). The markets in Europe and North America are less well-developed but are beginning to increase (Stanley et al., 2019). There is an increasing body of evidence that the consumption of algal food products may have health and nutritional benefits, though the nutritional composition and bioavailability and digestibility of macroalgae compounds is not fully understood (Buschmann et al., 2017; Wells et al., 2016). Care is also required around food safety standards if seaweeds are to be consumed in high amounts due to potential for adverse

health effects (for example from potentially high metal and iodine concentrations) (Stanley et al., 2019).

Animal feed

B.1.4 Seaweeds have been used for a long time as animal feed, particular for sheep, cows, pigs, horses (on the Orkney Islands, Scotland, there is a native breed of sheep feeding on seaweed on the shore) (Cefas, 2016). Commercially, seaweeds are added to animal feed as a supplement in the form of granules or powder, the amount of which is regulated under European legislation (Stanley et al., 2019). *Ascophyllum nodosum*, *Alaria* spp., *Laminaria* spp., *Palmaria* spp. and *Ulva* spp. are species commonly added to fodder after it is dried and milled, and is marketed as improving health, fertility and overall productivity of livestock (Stanley et al., 2019). Seaweed is also added as feed in either fresh or dried form in aquaculture, for example in abalone farming (note, not in Scotland) using *Ulva* and *Fucus* spp. (Bansemer et al., 2016; Stanley et al., 2019). Recent research has focussed on the potential to use red seaweed (*Asparagopsis taxiformis* naturally occurring in tropical/subtropical oceans), as a supplement within cattle feed to reduce the methane emissions from cattle (Roque et al 2019, 2021). A recent feasibility study in the UK has been undertaken to identify species of seaweeds that are found in the UK with similar potential for methane suppression[44].

Horticulture

B.1.5 Seaweeds can be used in horticulture as a fertiliser to encourage plant growth by providing a source of micronutrients (Cefas, 2016). This is usually applied in liquid form, whereby seaweeds are heated and pressurised to extract nutrients, though dried seaweed can also be used. Dried seaweed can also be applied

[44] SIF project summary for Halogenated Compounds in Seaweeds.

as a soil conditioner to allow greater water and air penetration (Mouritsen, 2013).

Hydrocolloids

B.1.6 Hydrocolloids are polymers used mainly in food products, but also in cosmetic and medical products (Cefas, 2016). They bind to water and form viscous dispersions or gels which are then used as additives and stabilisers across these sectors (Mouritsen, 2013). Three types of hydrocolloids can be extracted from seaweeds: alginates, which are extracted from brown seaweed (alginophytes); agar, which are extracted from red seaweed (agarophytes); and carrageenan which are also extracted from types of red macroalgae (carrageens).

Bioactives

B.1.7 Extracts from seaweeds have applications in health and personal care, and can be referred to as bioactives where they have a biological effect and promote good health. Examples of these products include the polysaccharides laminarin (extracted from brown algae) which have anti-bacterial properties (Anis et al., 2017), and fucoidans which have anti-viral properties (Hayashi et al., 2008). Other research suggests other bioactive compounds found in seaweeds have the potential to interact with cancers, the immune system, inflammation and pathogenic fungi (Cefas, 2016 and references cited therein). Hydrocolloids (described above) can also be used for medical purposes such as capsules for medicines, and making plasters or bandages (Cefas, 2016). Nutraceuticals can also be produced from seaweeds to improve heath. These are dietary supplements that contain the beneficial vitamins, minerals and essential trace elements, polyunsaturated fatty acids, bioactive metabolites, proteins, polysaccharides and dietary fibres contained within seaweeds (Ganesan et al., 2019). Seaweeds can also be incorporated into cosmetic products and range from simple dried seaweeds for home baths to high value spa and cosmetics ranges (Stanley et al., 2019). Much of the evidence for the efficacy of these cosmetic products is anecdotal, but research into bioactive

compounds contained in seaweeds substantiates their use in cosmetics (Stanley et al., 2019).

Biofuels

B.1.8 There has been considerable interest in the use of seaweed as a feedstock to produce biofuels. Kelps in particular, have been the focus of considerable interest due to advantages over traditional biomass for biofuels such high productivity, fast growth rates, and the fact they do not need land or freshwater to grow (reflected in the large number of funded research projects on algal biofuel technologies such as SeaGas) (Cefas, 2016). However, seaweed-based biofuels still face issues such as scalability and economic viability, and competitiveness and performance against other feed stocks need to be considered (Bruton et al., 2009; SARF, 2016; Stanley et al., 2019).

Bioremediation

B.1.9 Alongside extractive seaweed industries and products, seaweeds can be used for bioremediation purposes. As efficient absorbers of nutrients and contaminants, seaweeds can remove waste released from aquaculture installations (Cefas, 2016). This is often employed in aquaculture facilities to reduce pollution.

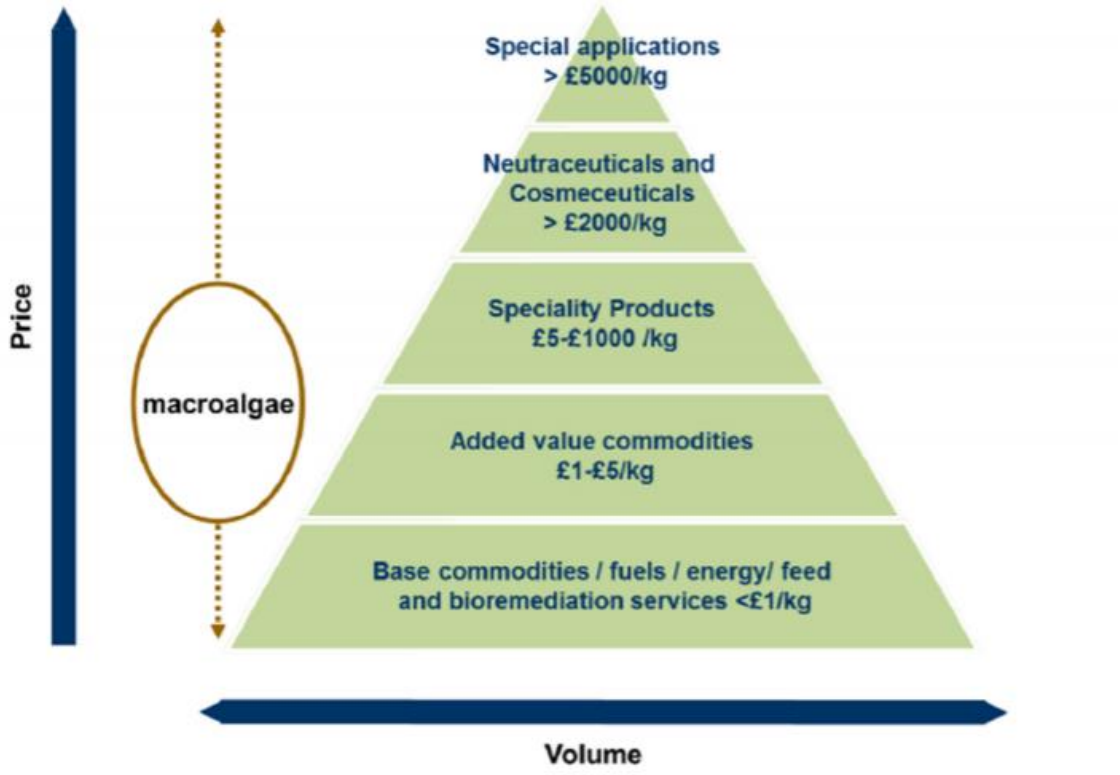
Biotechnology

B.1.10 There are other novel and innovative applications for seaweed that have not yet been taken up on a large scale and remain in development. This includes using seaweed as raw material (feedstock) for biotechnology processes, such as biorefining to extract a range of products (with a range of values) from the whole seaweed plant, and/or the production of biomaterials (such as bioplastic) to create alternative packaging materials. A biorefinery approach to seaweed production has been described by Cefas (2016), Stanley et al. (2019) and BIM (2020). It integrates a chain of production for different fuels and products to extract a range of high and low value products and optimises the processing of seaweed to improve production economics (Stanley et al., 2019). This process

allows access to different markets and reduces waste, thereby making production more viable (Cefas, 2016). This feeds directly into the concept of bio and circular economies which is advocated by some seaweed-related stakeholders and businesses already established in the UK.

B.1.11 The biorefinery approach extracts the most valuable components from algal biomass, leaving the remainder unadulterated for commodity purposes (food, feed, fertiliser, fuel) (Baghel et al, 2015; Trivedi et al, 2015 in Buschmann et al, 2017). As shown in Figure B1, production of fuels, energy, and animal feed require large volumes of seaweed but the price for the biomass is small around < £1 per kg. However, when algal components are used in high-value products, such as nutraceuticals and cosmeceuticals, the value of algae derived product becomes substantially higher at > £2,000 per kg, and up to > £5,000/kg for special applications (Cefas, 2016). In the UK, the current capacity for seaweed production sits between 'added value commodities' and 'speciality products' (Cefas, 2016).

B.1.12 The biorefinery approach may be an important concept for the future of the global seaweed industry, including Scotland. However, there are knowledge gaps in its application, encompassing biological and engineering challenges, bioprocessing technologies, environmental implications, sustainability issues, and policy and legislation hurdles (Stanley et al., 2019).



Source: Cefas (2016)

Figure B1. Pricing of products from macroalgae and current capacity for macroalgae production in the UK

B.1.13 The categories of seaweed-based products used within the main report are summarised in Table B1. Some of these categories overlap by virtue of their eventual end uses. For example, hydrocolloids are used in both human food products and pharmaceuticals and other personal care products. Equally, nutraceuticals might be considered as human food as products are ingested as a dietary supplement, although for the purposes of this study, they have been considered within the bioactive category. Table B1 also indicates which product categories were included within the socio-economic evaluation in the main report.

Table B1. Product categories for seaweed uses

Product category	Description	Scoped into the socioeconomic evaluation
Human food	Seaweed products that are intended for human consumption	Yes
Animal feed	Seaweed products that are incorporated into animal feed	Yes
Horticulture	Seaweed products to aid plant cultivation such as fertiliser and soil conditioners	Yes
Bioactives (cosmetics, pharmaceuticals, and nutraceuticals)	Seaweed products for use in personal care and health applications (cosmetics, pharmaceuticals, and nutraceuticals)	Yes
Hydrocolloids	Seaweed extracts such as alginates, agar, carrageenan	Yes
Biotechnology	Using seaweed as a feedstock for biotechnology processes that extract a range of high value products or novel products	Yes
Biofuels	The use of seaweed to produce energy and fuels	No
Bioremediation	The use of seaweed to remove nutrients and contaminants from water to improve water quality	No

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C Review of International Seaweed-based Industry Activity and Markets

C.1 Introduction

C.1.1 This appendix provides a brief overview of the global seaweed industry with respect to global seaweed production and uses. A series of case studies are then presented summarising information relating to the current status of the seaweed-based industry in other countries considered comparable to Scotland on the basis of their utilisation of the same or similar seaweed species for commercial purposes (Chile, Norway, France, Ireland, and Iceland), focussing on (where the information was available):

- Production methods (i.e. wild harvesting and/or cultivation), volumes and recent production trends;
- Species harvested/cultivated and products; and
- Product markets and value.

C.1.2 This information was then considered in the development of possible future scenarios for the Scottish seaweed-based industry, particularly with regard the supply of raw seaweed material and competition with regard to products and markets (see Section 6 in the main report).

C.1.3 It should be noted that in general, data relating to production volumes of seaweed (wild harvested or cultivated), markets and value were relatively sparse, out-of-date and/or inconsistent between sources. However, a summary of key points has been compiled at the end of the appendix.

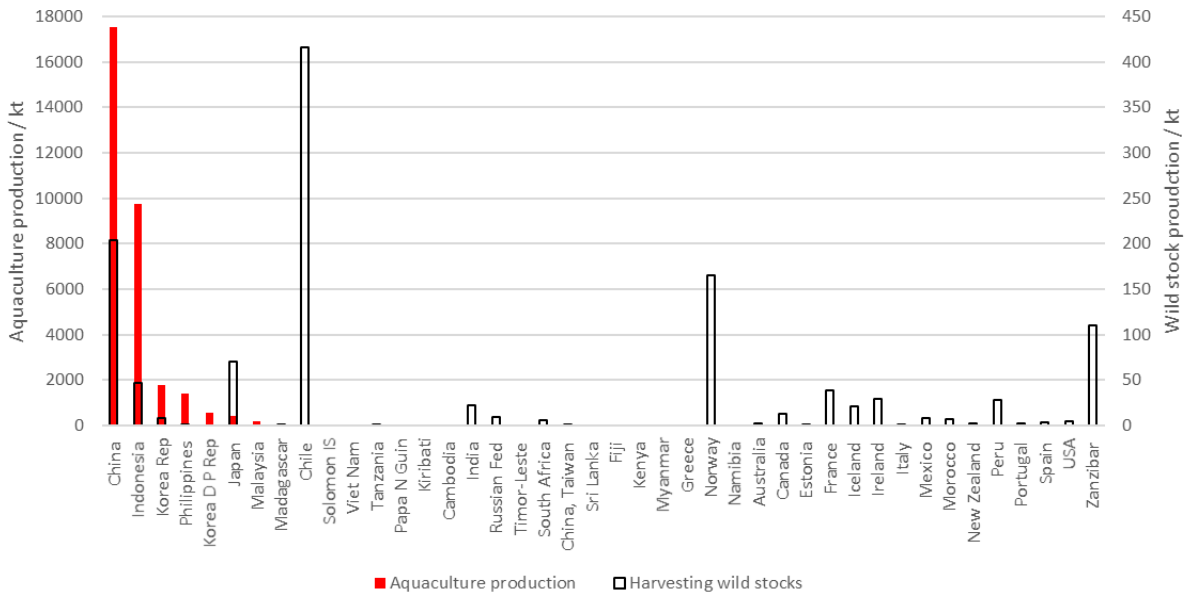
C.2 Global overview

C.2.1 The global seaweed industry has been estimated to be worth €8.1 billion per year (Barbier et al. 2019). Global production[45] of aquatic plants, mostly seaweeds, reached 32.9 million tonnes in 2017, of which 31.8 million tonnes (96.6%) was harvested from aquaculture (i.e. cultivated; FAO, 2019). This production of aquatic plants has grown from 13.5 million tonnes in 1995 (FAO, 2018). The production of seaweed (from cultivation and wild harvest combined) is dominated by Asian countries, primarily China and Indonesia, but with the Philippines, South Korea, Japan and Malaysia also being key seaweed producing countries (Cefas, 2016; FAO, 2018, FAO, 2019). The only countries outside of Asia that ranked within the top ten producers of marine aquatic plants (cultivated or harvested) in 2017 were Chile (1.3% of the 2017 total) and Norway (0.5%) (FAO, 2019).

C.2.2 Seaweeds are primarily cultivated (farmed) in Asia and Africa, as opposed to Europe and America where seaweeds are almost entirely harvested from the wild (Figure C1).

C.2.3 Globally, 97.4% of production is of red and brown seaweeds (Cefas, 2016). These types of seaweed increased in production by 84% and 47% respectively between 2010 and 2014 (Cefas, 2016). Green seaweed is produced in lesser quantities and has decreased in production by 30% between 2010 and 2014. The vast majority of European production is of brown seaweed.

[45] The term production in FAO statistics refers to the volume of aquatic plants harvested from the wild (also referred to as capture) and seaweed cultivated in marine, brackish and freshwater environments. The term is not specific to seaweed, although seaweed does constitute the majority of production.



Source: Adapted from FAO (2019)

Figure C1. Volumes of seaweed harvested from the wild and cultivated, by country in 2017

C.2.4 At the global level, approximately 85% of seaweed production comprises products for human consumption (FAO, 2018). The remaining 20% is used to extract hydrocolloids, and for animal feed, fertilisers, water remediation and probiotics in aquaculture (West et al., 2016). Seaweed derived extracts (carrageenan, agar and alginates) make up 40% of the world's hydrocolloid market in terms of foods, with the rest derived from certain animals, microbes and land plants (FAO, 2018).

C.3 Comparable country seaweed industry baselines

C.3.1 The overview of the scale, scope and value of the seaweed-based industry sectors in countries considered comparable to Scotland on the basis of their utilisation of the same or similar seaweed species for commercial purposes,

was based on a desk-based review, supplemented by consultation with relevant industry experts[46] from Scotland and other countries, where possible.

C.3.2 The countries (case studies) considered in this study were Chile, Norway, France, Ireland and Iceland. The general development of the seaweed-based sector in these countries, including the main seaweed species and tonnages produced (by wild harvest and cultivation where applicable), products and markets have been summarised below (where information was available) to assist in identifying potential future product and market opportunities for the Scottish industry as it seeks to expand and develop (see Section 6 in main report). As data relating to the scale (size and value) of the sector for these countries was relatively scarce (an issue raised in other recent reports e.g. BIM, 2020), aggregated information for Europe has also been included where available and considered to be relevant.

Chile – Trends in seaweed production

C.3.3 Chile is the biggest producer of algal commodities in South America, and the biggest outside of Asia, exploiting 16 species of seaweed (FAO, 2018). Including both wild harvest and cultivated seaweeds, Chile accounted for 1.3% of global production in 2017 producing 432,262 tonnes (FAO, 2019).

C.3.4 The majority of seaweed landings in Chile are wild harvested from natural beds (rather than cultivation) with Chile being the biggest producer of wild harvested seaweeds in the world (Cefas, 2016). These high seaweed production (harvest) rates have been driven by the development of the carrageenan industry, the increased production of agar, and the increasing interest for brown algae (Buschmann et al., 2008). Reported annual tonnages wild harvested between 2009 to 2017 are shown in Table C1. Historic fluctuations in seaweed production are the result of over harvesting and changing market demand

[46] Such contacts were determined through the desk-based review above and liaison with the Project Steering Group (PSG) and the Scottish Seaweed Industry Association (SSIA)

(Buschmann et al., 2008), as well as natural factors (for example earthquakes resulting in large-scale mortality of subtidal and intertidal organisms; Mac Monagail, 2017).

Table C1. Trends in wild harvested seaweed (tonnes) in Chile (2009-2017)

2009	2010	2011	2012	2013	2014	2015	2016	2017
368,032	368,580	403,496	436,035	517,929	417,331	345,704	329,707	415,463

Source: FAO (2019)

C.3.5 Cultivated seaweed production is relatively small-scale in Chile. Reported annual tonnages cultivated between 2009 to 2017 are shown in Table C2 and demonstrate notable inter-annual variation. Red seaweed *Gracilaria*, which is planted and harvested by fishermen, makes up the majority of cultivated seaweeds in Chile and is the only species to have reached commercial scale, although still only contributing to less than 5% of total seaweed production (from harvesting and cultivation combined) (FAO, 2018). Other seaweeds are farmed but only on an experimental basis in response to Government-led priorities to increase production levels to meet demand for algal commodities.

Table C2 Trends in cultivated seaweed (tonnes) in Chile (2009-2017)

2009	2010	2011	2012	2013	2014	2015	2016	2017
88,193	12,179	14,694	4,126	12,512	12,836	11,952	14,863	16,799

Source: FAO (2019)

Chile – Seaweed-based products

C.3.6 A variety of seaweed species in Chile are used as food products, animal feeds, or to produce carrageenan, agar and alginates. Species and uses are described by FAO (2018) and summarised in Table C3.

Table C3 Main seaweed species and products produced in Chile

Product Group	Product	Species	Further information
Human food	Various food products	Bull kelp Durvillaea antarctica	8,000 tonnes harvested in 2014; 400% increase 2004-2014; Found in coastal markets, sold by fishers, and in grocery supermarket chain in inland cities and towns
	Various food products	Purple laver *Porphyra* spp.	132 tonnes harvested in 2014; 1000% increase 2004-2014; Found in coastal markets, sold by fishers, and in grocery supermarket chain in inland cities and towns
	Various food products	Red algae of *Gigartinales* family	Primarily consumed abroad as seasoning in Asian dishes
	Various food products	Chondracanthus chamissoi	2,715 tonnes harvested in 2014 Second most produced seaweed in Chile for human consumption though trend declining
	Various food products	Callophyllis variegata	Less than one tonne harvested per annum Declining trend in production
Animal feed	Abalone feed	Lessonia trabeculata	Blades used for haliotid (abalone) foraging
	Abalone feed	Macrocystis pyrifera	Used for abalone feeding

Product Group	Product	Species	Further information
Hydrocolloids	Carrageenan	Gigartina skottsbergii	Symptoms of an over-exploited species Biomass regulated by an area rotation system (harvesting restricted in May-Sep) 15,000 tonnes harvested in Region XII, 55% national production
	Carrageenan	Sarcothalia crispata	34,600 tonnes harvested, mostly from Region X
	Carrageenan	Mazzaella laminarioides	Production does not exceed 5,000 tonnes per annum
	Agar	Gracilaria chilensis	45,000 tonnes cultivated in 2014; Comprises almost 100% of cultivated biomass; Planted and harvested by local fishers
	Agar	Gelidium spp.	Variable production, collected by fishers; 135 tonnes to 700 tonnes harvested in last decade
	Alginates	Lessonia nigrescens	430,000 tonnes harvested; Most produced seaweed
	Alginates	Lessonia trabeculata	60,000 tonnes harvested; Stipes used for alginate production
	Alginates	Macrocystis pyrifera	25,000 tonnes harvested

Source: Adapted from FAO (2018)

Chile – Markets and value of seaweed-based products

C.3.7 Information on the main markets for seaweed products from Chile and indicative market values of seaweed-based products in Chile is provided by FAO (2018) and is summarised in Table C4. The information illustrates how seaweed products that have undergone some processing and are of export quality sell at higher prices per tonne, in part due to water loss during the processing.

Table C4 Markets and value of seaweed species and products produced in Chile

Product type	Indicative value (2014 prices)
Fresh or air-dried harvested seaweed for human consumption (food products)	Sold to local and domestic markets by fishermen from the beach. The price is highly variable depending on availability and buying power of middle men, although some species (*Porphyra* spp. and *D. antartica*) that can be processed immediately and sold directly to local markets are higher value (typically US Dollar (USD) 1927 per tonne and USD 1718 per tonne respectively)
Seaweed for hydrocolloid extraction	Typically between USD 81 to 646 per tonne, except *Gelidium* which around USD 1540 per tonne due being more difficult to harvest and its particular agar composition
Dehydrated seaweed commodities (for food products)	For export markets. Relatively high value (due to water loss during processing), ranging from USD 1,305-4,472 per tonne
Food products	For export markets. Relatively high value due to the food regulations and processes that must be upheld. Typical prices in 2014 between USD 3,000-5,000 per tonne, although *C. chamissoi* for human consumption reached USD 28,000 per tonne in 2014.
Hydrocolloids (carrageenan and agars)	The main goods of value exported to over 50 countries. Approximate values: Agar USD 27,000 per tonne (total export value USD 49 million; 53% total sold to Japan) Carrageenan USD 15,000 per tonne (total export value USD 72 million; 60% sold to Denmark and the USA)

Product type	Indicative value (2014 prices)
Dried seaweed for hydrocolloid extraction	For export markets. Highest value species *Lessonia* with average annual FOB* export value of over USD 83 million between 2013-2016. 80% exported to China. Other important markets included Canada, Denmark, France, Japan and Norway.

Source: FAO (2018)

Norway – Trends in seaweed production

C.3.8 Norway is the largest producer of seaweeds in Europe, contributing 0.5% of total world production in 2017 (FAO, 2019). Wild seaweed harvesting is the primary means of producing seaweed in Norway, accounting for 14.8% of global production from wild harvest sources in 2017 (FAO, 2019). This placed Norway as the third largest producer of wild harvested seaweed globally (behind Chile and China).

C.3.9 Reported annual tonnages wild harvested between 2009 to 2017 remained relatively stable and are shown in Table C5.

Table C5 Trends in wild harvested seaweed (tonnes) in Norway (2009-2017)

2009	2010	2011	2012	2013	2014	2015	2016	2017
154,215	160,361	158,516	152,382	140,998	154,150	154,230	147,391	169,407

Source: FAO (2019)

C.3.10 More recently, BIM (2020) reported that around 150,000 wet tonnes of *Laminaria hyperborea* (average price €23/wet tonne) is wild harvested each year, to produce around 5,000 tonnes of alginate. Around 10-20,000 wet tonnes of *A. nodosum* are also wild harvested per annum (average price around €50/wet tonne) predominately for use in seaweed meal (feed), agriculture, nutraceutical and cosmeceutical products. A small amount of the green seaweed *Ulva lactuca* is harvested for the restaurant trade (c. €50/kg).

C.3.11 *L. hyperborea,* is harvested with a rake-type dredge that is pulled by a boat which removes the kelp plants from the rock (Burrows *et al*., 2018). *Ascophyllum nodosum* and *Laminaria digitata* are also mechanically harvested in Norway's waters (EUMOFA, 2019).

C.3.12 Until relatively recently, cultivation of seaweed was not generally being undertaken in Norway. The country was early to develop a knowledge-based, integrated coastal zone management system, and it was recognised that the growing demand of the seaweed industry could not be satisfied solely from the wild (Stévant et al., 2017). Pilot farms were set up to investigate upscaling biomass production (Cefas, 2016). This moved quickly to obtain commercial permits for cultivation of mainly *Saccharina latissima* in coastal water (Stévant et al., 2017). As summarised by Stévant et al. (2017), the first commercial cultivation permit at sea in Norway was issued in 2014. This follows the creation of a specific-interim-licensing system.

C.3.13 Since 2015 the number of licences granted for the cultivation of seaweeds, companies involved and tonnages harvested from farm sites have all gradually increased in Norway (BIM, 2020). By the end of 2018 there were 406 licences for seaweed cultivation (78 for *S. latissima*, 70 for *L. digitata*, 75 for *Alaria esculenta* and 60 for *Palmaria palmata*, with the other 133 licences for other seaweed species or 'mixed' licences). Of the 406 licences, 155 were active (operational), with 20 companies cultivating seaweed across 83 sites (BIM, 2020).

C.3.14 In 2016, the total surface area licensed for seaweed cultivation at sea reached 277 ha, which is thought to equate to 16,000 tonnes of production, though that level is not reached as most companies are in the start-up phase of production (Stévant et al, 2017). In 2018, BIM (2020) reported that 169 wet tonnes of cultivated seaweed were harvested (total value c. €120,000) comprising 165 wet tonnes *S. latissima* (€450/wet tonne) and 2 wet tonnes each of *A. esculenta* (€3,100 and €3,800 / wet tonne in 2016 and 2017 respectively) and 'other seaweeds'.

C.3.15 There are plans in Norway to develop large scale cultivation and establish a sustainable seaweed value chain from the cultivated biomass (BIM, 2020).

Current efforts regarding industrial scale of cultivated production, mainly of sugar kelp *S. latissima,* are focussed on developing efficiencies that reduce the need for maintenance and improving technologies such as mechanising seedling deployment and harvest and crop handling (Stévant *et al.,* 2017).

C.3.16 Industry groups (e.g. Norwegian Seaweed Farms) and an industry-led project (SEABEST) have been set-up, the latter to develop a commercial seaweed supply chain primarily to supply high quality food products to European markets, but also to explore opportunities for new products and markets in bioenergy, pharmaceutical and animal nutrition (BIM, 2020). The Norwegian Seaweed Biorefinery Platform[47], a five-year research programme funded by the Research Council of Norway, is a national consortium generated to coordinate the efforts of research institutions toward an increased and sustainable Norwegian seaweed-based industry. The focus of the research is on characterisation of the seaweed biomass (e.g. chemical composition) and the development of technology for biorefinery processes and establishment of high-value and bulk product pipelines.

Norway – Seaweed-based products

C.3.17 The main seaweed product in Norway is alginates, which is primarily produced from the wild harvested kelp *L. hyperborea*.

C.3.18 Processing industries often locate close to seaweed harvesting areas, to limit the cost of transporting wet material and remain competitive with the importation of dried material (EUMOFA, 2019). The largest European alginate extraction facility is located in Norway, operated by DuPont, and accounts for around two thirds of the total European alginates production (European production of alginates amounted to around 10,000 tonnes in 2017 and this production covers most of the European demand for alginates CBI, 2018). The

[47] Norwegian Seaweed Biorefinery Platform website.

European extraction facilities mostly produce food-grade alginates with a high gelling strength (i.e. sodium alginate).

C.3.19 Cultivated *A. esculenta* is often sold in dried or fresh form as a high value food ingredient (sea vegetable), whereas *S. latissima* has a broader range of market outputs, such as being dried for human consumption or used as meal in animal feed (Stévant *et al*., 2017).

Norway – Markets and value of seaweed based products

C.3.20 The market value of the alginate industry in Norway was not readily available in the literature reviewed.

C.3.21 As noted above, reported values of cultivated *S. latissima* in 2018 and *A. esculenta* in 2016/17 were €450 and €3,100 – €3,800 per wet tonne respectively (BIM, 2020). When comparing the retail value of these species in an earlier report (USD 399 per tonne for *S. latissima* and USD 1,099 per tonne for *A. esculenta* in 2015), Stévant *et al*., (2017) stated the higher value of *A. esculenta* may be attributed to the fact it is often sold in dried or fresh form as a high value food ingredient, whereas *S. latissima* is usually dried for human consumption or used as meal in animal feed (although, no information was available regarding the retail markets of the produced biomass). It was suggested that the lower biomass available on the market may also explain the higher value of *A. esculenta* (Stévant *et al*., 2017).

France – seaweed production trends

C.3.22 France is the second largest producer of seaweeds in Europe (BIM, 2020). Almost all of the production in France comes from wild harvested rather than cultivated seaweed.

C.3.23 France is a country that has seen the biggest growth in wild harvested production over recent years, with a large increase in production between 2009 and 2013, although tonnages have fluctuated since (Table C6). Mesnildrey *et al*. (2012) state that landing volumes for *L. digitata* (the most harvested species in France) are dictated by the processing industry in relation to their capacity to

process fresh algae (with treatment plant capacities ranging from 40,000 to 47,000 tons), although it is not clear whether this fully accounts for the fluctuations in harvested wild seaweed tonnages shown in Table C6.

Table C6 Trends in wild harvested seaweed (tonnes) in France (2009-2017)

2009	2010	2011	2012	2013	2014	2015	2016	2017
18,907	22,597	47,307	41,229	69,126	58,512	19,110	55,041	39,072

Source: FAO (2019)

C.3.24 The species *L. digitata* and *L. hyperborea* are harvested in the highest quantities (Mesnildrey *et al*., 2012). These authors reported approximately 40,000 to 60,000 tonnes of *L. digitata* had been harvested annually between 2008 to 2011, with around 10,000 to 20,000 tonnes of *L. hyperborea* harvested (it is noted that these volumes do not appear to correspond with the volumes shown in Table C6). These species are harvested mechanically by fishing vessel (using a rake type dredge known as a "scoubidou") (EUMOFA, 2019). Another species that is harvested is *Gelidium sesquipedale* which is primarily gathered as beach cast material (Mesnildrey *et al*., 2012).

C.3.25 Cultivated seaweed production in France has been on a relatively small scale (< 100 tonnes per annum) until 2009, after which production of 'miscellaneous aquatic plants'[48] increased up to around 380 tonnes in 2011 (Cefas, 2016). BIM (2020) reported that there were ten companies with cultivation capability in France, mainly farming *Undaria pinnatifida* and *S. latissima*, and that up to 50 tonnes (wet weight) of seaweed was cultivated per year. However, the authors highlighted the discrepancy between the cultivated tonnage they reported and the FAO statistics which reported 500 tonnes per year. BIM (2020) also

[48] The type and species of aquatic plant was not identified in Cefas (2016). As they are not included under brown, red or green seaweeds, it is assumed that this does not refer to the production of seaweed (macroalgae).

reported that France was making substantial investment in research to develop cultivation of key seaweed species.

France – Seaweed based products

C.3.26 The chemical and food-processing industries (i.e. hydrocolloids) are the main markets for seaweed in France, with 75% of the harvested seaweed (domestic production and imports) used for this sector (Mesnildrey *et al*., 2012). The rest is used for agricultural purposes, water treatment and health care products (cosmetics and pharmaceuticals), and a small proportion is produced for direct human consumption (Mesnildrey *et al*., 2012). Further information on specific species and products are presented in Table C7. Limited information was available regarding the tonnage of species harvested or cultivated to contribute to each product group.

C.3.27 In 2012, Mesnildrey *et al* (2012) reported that approximately 90 companies process or sell products made using seaweed in France. Of these companies, nearly half (40) used seaweed within the 'health and wellbeing' sectors (i.e. within the cosmetic and pharmaceutical industries; classified within the bioactive product group in this study), approximately 25% within the agricultural supply and water treatment sectors, approximately 25% provided seaweed as vegetables for human consumption and approximately 8% (7 companies) produced hydrocolloids. Consultation undertaken for this study referred to two companies in France currently producing alginates from seaweeds (almost entirely from *L. digitata*): Algaia and Rettenmaier (JRS) (stakeholder pers. comm.).

C.3.28 Similar to Norway, the processing industries in France have located close to seaweed harvesting areas with the two main companies in north-west Brittany (EUMOFA, 2019). However, as noted in Table C7, local seaweed production in France is not always sufficient to meet the demands of local processing industries (especially for alginate production), so raw material is also imported when local supplies are out of season or insufficient (EUMOFA, 2019). The import of algae unfit for human consumption experienced a strong increasing trend from 2012 to 2016 from approximately 1,123 tonnes to nearly

18,000 tonnes (FAO, 2018). This increase may be attributed to the need to supply the processing industry as well as a decrease in wild harvesting production in France in 2015 and 2016 (EUMOFA, 2019; FAO, 2018). At the same time, the average import price dropped 38%, falling from € 205 per tonne to € 128 per tonne (EUMOFA, 2019).

Table C7 Main seaweed species and products produced in France

Product Group	Product	Species	Further information
Food	Sea vegetable	Palmaria palmata (dulse)	France is a major producer of dulse
Food	Various food products	*A. nodosum* (egg wrack) *Fucus vesiculosus* (bladder wrack) *Himanthalia elongate* (thong weed) *Undaria pinnatifida* (wakame) *Laminaria digitata* (oarweed) *Laminaria saccharina* (Sugar kelp) *Laminaria japonica* (kombu) *C. crispus* (Irish moss) *Porphyra* spp. (7 species) *Gracilaria verrucose* *Ulva lactuca* (sea lettuce) *Enteromorpha* (gut weed)	Up to 20 species are considered as edible as raw material or an intermediary product for the food processing industry Edible seaweed species are often cultivated or gathered on shore, mainly by occasional (rather than professional) gatherers

Product Group	Product	Species	Further information
Bioactives	Various cosmetic and pharmaceutical products	*A. nodosum* (egg wrack) *Fucus vesiculosus (*bladder wrack*)* *Himanthalia elongata* (thong weed) *C. crispus* (Irish moss) *Pelvetia* sp. *L. digitata* (oarweed) *Palmaria palmata* (dulse)	No information was found regarding the source of the seaweed material (wild harvested or cultivated) or the volumes used
Animal feed	Various products	*A. nodosum* (egg wrack) (main species) *Fucus* spp. (wracks)	Up to 6,000 tonnes *A. nodosum* harvested annually, mainly for use in feed and fertiliser although this species can also be used in alginate production
Fertiliser	Various products (including powders and liquid extracts)	*A. nodosum* (egg wrack) (main species) *Fucus* spp. (wracks)	As above
Hydrocolloids	Alginates	*L. digitata* (oarweed) (main species) *L. hyperborea* (cuvie) *A. nodosum* (egg wrack)	Between 40,000 and 60,000 tonnes *L. digitata* harvested annually (reported in 2012)

Product Group	Product	Species	Further information
			Import dried seaweeds when local supplies are out of season or not enough to meet demand Used in textile and food-processing industries as well as numerous other products
	Agar-agar	*Gelidium sesquipedale*., *Gracilaria* spp. *Porphyra* sp	Used for microbiological work and food processing
	Specialty carrageenan	*Chondrus crispus Mastocarpus stellatus*	Used particularly in manufacturing of dairy products Carrageenans extracted from imported red algae from Asia (*Kappaphycus* and *Eucheuma*) are used in pet food

Sources: Misnildrey et al (2012); Cefas (2016), EUMOFA (2019)

France – Markets and value of seaweed-based products

C.3.29 Mesnildrey *et al*., (2012) reported that between 40,000 and 60,000 tonnes of *L. digitata* was wild harvested annually in France with an associated turnover of around € 1.7 to 2.7 million (note, the years to which these statistics apply was not stated).

C.3.30 A growing market in Europe is seaweeds for human consumption. This is in response to increasing demand for edible seaweed from European customers (EUMOFA, 2019). France supplies 90% of the European market for *Palmaria palmata* (dulse) (Cefas, 2016). Approximately 300 occasional gatherers harvest seaweed for a turnover of € 300,000 (Mesnildrey *et al*., 2012; year(s) not stated).

Ireland – Trends in seaweed production

C.3.31 The data presented by FAO (2018; 2019) and Cefas (2016) for seaweed production in Ireland appears to be estimated rather than actual reported production volumes. According to these reports wild harvested seaweed production totalled 29,500 tonnes in 2017 having remained constant from 2009. Almost all harvesting of seaweeds in Ireland is by hand, with around 6,500 private rights to harvest seaweed from the intertidal (ABPmer, Land Use Consultants & Plymouth Marine Laboratory, in prep), although mechanical harvesting is beginning to emerge (Mac Monagail and Morrison, 2020).

C.3.32 Irish production (wild harvest) of mainly brown seaweeds amounted to 32% of EU production in 2014 (EUMOFA, 2019), and 11% of the overall European seaweed market in 2016 behind Norway and France (Mac Monagail and Morrison, 2020). The majority of wild harvesting production is of brown seaweeds, with red seaweeds having accounted for < 0.5% of the total national landings by volume (approximately 100 tonnes) in Ireland in 2016 (Mac Monagail and Morrison, 2020).

C.3.33 *A. nodosum* is harvested manually in Ireland, sourced from the west coast (EUMOFA, 2019). This is the primary species harvested in Ireland accounting for 95% of seaweed landings in 2016 (Mac Monagail and Morrison, 2020).

Approximately 16,000 tonnes of this wrack per year are currently cut by hand in Connemara (County Galway) and in County Donegal (Guiry, 2020). Approximately 1,400 tonnes of *L. hyperborea* was harvested from wild stocks in 2016 (Mac Monagail and Morrison, 2020).

C.3.34 Relatively little seaweed production comes from cultivated sources in Ireland. Total cultivated tonnage was reported to increase from 3 tonnes in 2011 to 8.5 tonnes in 2012 and to 41.5 tonnes in 2013, comprising red and brown seaweeds (Cefas, 2016). The BIM seaweed development programme (operating since 2004) has focussed on perfecting cultivation methods for *A. esculenta, L.digitata*, *S. latissima* and recently the "sought after" red seaweeds *P. palmata* and *Porphyra* umbilicalis.

C.3.35 BIM (2020) reported that in 2018, 40 tonnes of cultivated seaweed was produced in Ireland that was worth €40,000 at farm gate (first sale), suggesting a value of €1,000 per tonne[49]. The species composition of this total tonnage and value was not specified (although the report later states that *A. esculenta* is farmed at licensed marine sites) however, it was noted that the seaweed was destined for high niche markets (not described) and hence further value added. It was estimated that there is 150 ha of licensed seaweed cultivation capacity in Ireland, which when fully operational (anticipated within 5 years) could produce 900 tonnes of farmed seaweed (BIM, 2020).

C.3.36 To satisfy the demand of the processing industry, dried seaweed is imported to Ireland when local supplies are out of season or insufficient. In Ireland, the import volume of seaweeds increased between 2012 and 2015 from 3,000 tonnes to 46,000 tonnes, mainly to supply the processing of animal feed and fertiliser (EUMOFA, 2019).

[49] Information from the stakeholder consultation indicated that cultivated seaweed could command a higher price compared to wild harvested seaweed due to a 'higher quality' product.

C.3.37 Both mechanical harvesting of wild seaweeds (using rakes from boats for *Ascophyllum* and the use of mechanical harvesting for kelps) to augment traditional hand harvesting and cultivation of seaweeds is expected to increase in Ireland. This is to take advantage of markets in cosmetics, nutraceuticals, pharmaceuticals, and food (Mac Monagail and Morrison, 2020).

Ireland – Seaweed-based products

C.3.38 It is estimated that there are 43 seaweed-based companies in Ireland, ranging from seaweed farm operators to businesses producing 'sea vegetables' (approximately 15 companies) and high end value added products such as plant biostimulants, soil amendments, animal health and nutrition products and cosmetics (BIM, 2020).

C.3.39 Alginates are produced from *A. nodosum*[50], and from *L. hyperborea*, mostly in export markets as Ireland does not produce alginate in great quantities (Guiry, 2020).

C.3.40 Seaweeds are also used to produce soil conditioners and for the production of liquid seaweed extracts, particularly from *A. nodosum,* for example fertiliser manufactured by Sea Chem (Shropshire Seaweed)[51].

C.3.41 Seaweed for human consumption (from wild harvest) has also increased recently, with a small number of companies operating in Ireland (EUMOFA, 2019). The main species used in Ireland include *P. palmata* and carrageenan moss (*C. crispus* and *M. stellatus*), with *S. latissima*, thongweed *Himanthalia elongata* and *A. esculenta* becoming more popular (Guiry, 2020). *P. palmata* is considered a delicacy in Ireland and 15 to 30 tonnes is consumed per year (Walsh and Watson, 2011).

[50] Previously half of dried *A. nodosum* production was exported to Scotland for alginate production, but alginate in Scotland has now ceased.

[51] Shropshire Seaweed website.

C.3.42 There are also some examples of specialised local companies using seaweeds (e.g. *Fucus serratus* and *A. nodosum*) in beauty products and treatments but in small quantities (Guiry, 2020).

Ireland – Markets and value of seaweed-based products

C.3.43 In 2012, it was estimated that the value of wild harvested seaweed (29,500 tonnes comprising 28,000 tonnes *A. nodosum, 1*,400 tonnes *L. hyperborea* and 100 tonnes of red seaweed) was €3.9 million (Norton *et al.*, 2014 and references therein). As noted above, recently introduced mechanised harvesting techniques and an expansion of seaweed cultivation in Ireland are anticipated to enable opportunities in the cosmetics, nutraceuticals, pharmaceuticals, and food markets to be accessed (Mac Monagail and Morrison, 2020).

Iceland – Seaweed production trends

C.3.44 All seaweed production from Iceland comes from wild harvested sources (Cefas, 2016). In 2017, Iceland harvested 21,313 tonnes of seaweed (1.92% of global wild harvested seaweed; 10th largest producer in the world) (FAO, 2019).

C.3.45 Overall, seaweed production (wild harvest) has remained relatively stable between 2009 and 2017 (Table C8).

Table C8 Trends in wild harvested seaweed (tonnes) in Iceland (2009-2017)

2009	2010	2011	2012	2013	2014	2015	2016	2017
22,563	21,014	15,737	18,079	17,168	18,427	16,830	17,985	21,313

Source: FAO (2019)

C.3.46 Harvesting of *A. nodosum* makes up the majority of seaweed production in Iceland. Kelps, primarily *L. digitata* as well as *L. hyperborea* are also harvested. Maack (2019) summarises more recent trends the harvested volumes of these species. The only large-scale harvester in Iceland is a company called Thorverk. Thorverk harvested approximately 19,800 tonnes of *A. nodosum* in 2018, demarcating an overall increasing trend in harvesting since the company began in 1975. This is reportedly attributable to increased market interest and the expansion of recommended harvesting volumes set by the Marine & Freshwater Research Institute (MFRI) (from 20,000 tonnes to 40,000 tonnes). *A. nodosum* is cut with specialised equipment without destroying plants' holdfasts or substrates.

C.3.47 Kelp harvesting by Thorverk has decreased from 3,700 tonnes in 2004 to 1,700 tonnes in 2018 (Maack, 2019). It is suggested that this is due to less market interest due to natural heavy metal content. It is also expensive to dry and needs a high-paying market (Eamer, 2016). Kelps are harvested using a vessel equipped with a rake-type dredge (Lee, 2018).

C.3.48 One other harvesting company in Iceland is operational (Íslensk Bláskel), but this is of a comparatively small scale, harvesting by hand (Maack, 2019).

Iceland – Seaweed based products and markets

C.3.49 Seaweeds from Iceland are generally sold as a raw material to other countries to be used in animal feed production, fertilisers and as alginates (Maack, 2019). The harvested kelp is mostly used for alginate production and animal feed, as well as in bath products and cosmetics (bio-actives, cosmetics) (Lee, 2018). Alginates derived from the seaweed are also used in beverages, cosmetics, medicines and in biotechnology (Maack, 2019).

C.3.50 As summarised by Maack (2019), Thorverk exclusively harvests seaweed by mechanical harvesting techniques. The seaweed is brought to shore where it is weighed and dried with geothermally sourced heat. Dried seaweed is then ground into seaweed meal or finer particles before exporting as organic fertilisers and animal feed (Lee, 2018). The feed product is exported to North

America and Europe and some amount for the production of alginate in Norway (Lee, 2018).

C.3.51 Íslensk Bláskel harvests seaweed by hand, followed by drying process to be sold to food and skincare industries (Maack, 2019).

C.3.52 No information was sourced regarding the economic value of these markets.

C.4 Scale and structure of the seaweed-based industry in Europe and Nordic countries

C.4.1 Further information on the scale and structure of the seaweed-based industry in Europe, and Nordic countries (Norway, Iceland) is provided by the European Commission's Knowledge Centre for Bioeconomy (KCB), which undertook an initial exercise to map macroalgae production units in Europe (KCB, 2019)[52]. Eighty one companies were identified that produced (harvested and/or cultivated) macroalgae. The highest number of companies were based in Ireland (17), France (14), Norway (11) and Spain (10) (8 companies were identified in the UK at that time) (see Figure 13; KCB, 2019).

C.4.2 The seaweed-based industry in countries in the North Sea basin (France, Belgium, Netherlands, Germany, Denmark, Norway and the UK) and the Atlantic sea basin (Iceland, Ireland, France, Spain) are reported to comprised a small number of relatively large companies (small to medium enterprises (SMEs))[53]. In general, the companies utilise wild harvested brown seaweeds (in EU waters) and red seaweeds (cultivated in Asia) and process them for the mature (established) hydrocolloid markets mainly for food and cosmetics. In the Atlantic basin countries, there were stated to be several global leaders on seaweed-based fertilisers also. In this area, it was noted that there were two

[52] The report noted that statistics on macroalgae biomass production (from the FAO and Eurostat) are incomplete and the dataset will be updated with new information as it becomes available.

[53] EU Seaweed Strategy, 11 June 2020; presentations available online.

plants to process brown seaweeds and three plants to process red seaweeds (the specific country or countries were not stated), and, in this data source, France was considered to be the main 'collector' and processor of seaweed. It was estimated that there were a small number of licences for sea-based cultivation of seaweed (approximately two in Ireland, four in France and a 'few' in Iceland, although it was noted there may be others), whilst in France there was one main established company (Alga+) undertaking land-based cultivation with several other land-based cultivation initiatives underway in France and Ireland. Although the sector in the Atlantic basin comprised mature companies at different levels of the seaweed chain, it was noted that the sector was still not well co-ordinated. It was anticipated that the future product/market focus of the sector in this region would be on bioactives, by-product valorization[54], biorefinery processes and the development of biomaterials.

C.5 Summary

C.5.1 In terms of wild harvested seaweed, kelps dominate production (harvest) in Chile, Norway and France where they are mainly used to produce alginates. The physical properties of alginate, which influences its application within the food and chemical industries, vary depending on its uronic acid composition (the ratio of mannuronic acid to guluronic acid; the M/G ratio). On a global scale, approximately 40,000 tonnes of alginate is produced annually, the vast majority of which is high M alginate (properties low gel strength, elastic gel), which Chinese companies can supply at very low costs compared to the European producers (information from stakeholder input). The remaining alginate produced is high G alginate (properties high gel strength, brittle gel). Norway hosts the largest alginate extraction facility in Europe (Dupont) and produces around two thirds of total European production and almost all of the global supply of high G alginate. The global size and value of the hydrocolloid market in 2016 (excluding China) was estimated at €488 million for agar

[54] Post-processing of by-products

(55,000 tonnes), €258 million for carrageenan (13,000 tonnes) and €237 million for alginate (16,000 tonnes) (CBI, 2018).

C.5.2 The use of seaweeds as food products is established in Chile and France and is likely to increase. This is due to growing interest in the sea vegetable market in western countries in Europe. In 2013, the wholesale value for sea vegetables was estimated to be €24 million (Organic Monitor, 2014). The use of seaweeds in bio-active products as (cosmetics, nutraceuticals, and pharmaceuticals) is also expected to grow.

C.5.3 In contrast to Chile, which farms relatively large volumes of red seaweed (*Gracilaria*) for agar production, seaweed cultivation in Europe is still only just emerging and is small-scale. Production of cultivated seaweeds has remained steady in Chile, and has fluctuated in France. In Norway and Ireland, cultivation seems to be slowly increasing. Species cultivated in European countries mainly include *S. latissima, A. esculenta* and *U. pinnatifida* for use in human food and animal feed.

C.5.4 A brief summary of the key points from this review is provided in Tables 2 and 3 in Section 3 of the main report. The implications of the scope and scale of the seaweed-based industry in these countries is considered further in Section 6 of the main report.

C.6 References

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D Industry Questionnaire

ABPmer and RPA are undertaking research for Marine Scotland and Crown Estate Scotland to better understand the potential scale of seaweed-based industries in Scotland. This research will feed into the Scottish Government's Seaweed Review and is considered key to ensuring that the review's wider research needs are grounded in where future opportunities for the sector may lie, balanced with consideration for the environment and those sharing the space.

These questions are designed to enable us to accurately document the current level of seaweed-related industry that exists in Scotland and project the potential future growth of the industry over the next 20 years, taking account of likely opportunities and constraints, as well as your vision of how you would like or expect the sector to develop.

A member of ABPmer's project team will call you to go through these questions with you so you do not have to fill in and return the questionnaire.

Any information that you provide will be treated as confidential under a non-disclosure agreement. The outputs of the research will be presented in an aggregated and anonymised format so that no information can be personally identifiable to your business.

Your current business

1. **Brief overview of your business**
    a. What seaweed product(s) do you produce?
    b. What proportion of your business/products relates to seaweed?
    c. Who do you sell your product to (e.g. processors, wholesalers, retailers, direct to consumers) and in what proportions (e.g. <25%, 50%, 75%, 100%)? Where are they located in Scotland (or in the rest of the UK/other)?

2. **Raw material**
    a. If you wild harvest the raw material for your product(s) in Scotland:
        i. What species?
        ii. How is it harvested?
        iii. In which months is harvesting undertaken?
        iv. What volume is harvested (e.g. per annum; wet weight or dry weight)?
        v. Where (general location) is harvesting undertaken?

    b. If you cultivate (farm) the raw material for your product(s) in Scotland:
        i. What species and why cultivate rather than harvest?
        ii. What size is the farm (e.g. number of ropes, hectares)
        iii. How do you long is the seaweed grown before harvesting and in which months is it harvested?
        iv. What volume is harvested (e.g. per annum; wet weight or dry weight)?
        v. Where is the cultivation taking place (general location)?

    c. If you do not currently cultivate raw material in Scotland - do you anticipate the need to, or intend to cultivate seaweed in the near future? If yes:
        i. What species and why?
        ii. What proportion of your raw material needs do you aim to cultivate?

d. If you do not obtain your raw material from wild harvest or cultivation in Scotland – how do you source your raw material?
    i. What species, quantities and where from?

3. Processing and supply chain requirements

a. If you process the raw material:
    i. What processing is undertaken? Please describe the process
    ii. Where is the processing undertaken?

b. If you do not process the raw material:
    i. Who do you sell it to?
    ii. Where are they based and how do they process it?

c. What other supply chain requirements do you have e.g. equipment, distribution to customers, others (describe)? What proportion is sourced from Scotland?

4. Products and markets – for your main products

a. How much of your product(s) do you sell per annum (please specify units)?
b. What is the unit price of your product? Or alternatively what is the turnover associated with this production?
c. Is annual production steady or can it vary significantly year on year (please provide numbers for the last 3 years)?

5. Costs and staffing

a. What are your operational costs on average per annum?
b. How have these costs changed over the last three years?
c. What is your capital expenditure? How often do you incur this? If possible, please provide the last year your investment took place.
d. How many full-time equivalent staff do you employ?

6. Constraints

a. Are there any factors currently constraining your business (e.g. in relation to scaling-up/economies of scale, licensing processes or conditions, technology, supply chain logistics or capacity, other – please describe)?

<u>Future plans for your business</u>

In order to project potential future growth scenarios, we are keen to understand your vision for your company and then more broadly for the seaweed industry in Scotland.

7. Vision for company

a. Do you anticipate expanding production of current products? If yes:
    i. Is this related to increasing demand in your current market and/or new markets?
    ii. How much do you anticipate increasing production by and when?
    iii. How much additional raw material would be required? Would this be achieved through harvesting and/or cultivation (or other)?
    iv. Where would you source your raw material from?

b. Do you anticipate creating new products? If yes:
    i. What type of product(s)?
    ii. What additional raw materials will be required (species, volume, location)?
    iii. Is there enough resource to accommodate this?
    iv. Would your processing techniques and supply chain need to change and, if so, when and how (techniques, location)?
    v. Would the costs of your operation change and if so, when and by how much?
    vi. What markets would you target and what is the expected export volume and turnover (e.g. per annum)?

8. Constraints and opportunities
    a. What (if anything) may potentially constrain your business in the future and why? For example:
        i. Resource availability?
        ii. Staff recruitment?
        iii. Seasonal variation in resource supply or quality?
        iv. Demand for product?
        v. Processing and supply chain capacity or costs?
        vi. Harvesting/cultivation techniques and their environmental impacts?
        vii. Licensing and regulation?
        viii. Other?

9. The future of the seaweed industry in Scotland
    a. More broadly, how do you see the seaweed industry developing in Scotland over the next 20 years? Where do you see the main opportunities arising?

E Status of the Current Seaweed-based Industry in Scotland – Method and Detailed Results

E.1 Introduction

E.1.1 This appendix provides further detail on the approach to, and outcomes of, the desk-based review and stakeholder consultation undertaken to inform the Scottish seaweed-based industry baseline presented in Section 4 of the main report.

E.1.2 The baseline information presented is based on information sources reviewed and 22 interviews with seaweed-based businesses and wider stakeholders, conducted in early 2020. It is therefore important to note that the baseline presented is based on information provided at that time and as such may underestimate the current level of activity. This is acknowledged as a limitation of the study in Section 4 of the main report.

E.2 Historic Context

E.2.1 Seaweed harvesting in Scotland has been ongoing for hundreds of years, being used as fertiliser for poor coastal soils, and for soda ash derived from burning kelp and wracks (Angus, 2017). Its main industrial use was for a source of phycocolloids; alginates were first extracted from seaweed in Scotland in 1883 but industrial production was not established in Scotland until 1930 by Cefoil in Kintyre (Burrows et al., 2018). This industry expanded and factories were built in Kames, Barcaldine and Girvan during World War II with new seaweed sources obtained from Norway, Iceland, Chile and Tasmania (Burrows et al., 2018).

E.2.2 As summarised by Burrows et al. (2018), in the late 1970s the alginate industry began to decline in Scotland due to increased competition from China. The Scottish alginate industries were taken over by Kelco/Alginate Industries Ltd. and the Barcaldine plant was closed in 1996 with Scottish alginate production concentrated in Girvan. The alginate arm of Kelco was then sold to International Speciality Products (ISP) in 1999, who then sold the alginate

business in 2009 to FMC Corporation which became part of Pronova, a Norwegian producer. The factory at Girvan was downgraded from production to product blending/finishing, with production moved to Norway and with raw material supply coming from Iceland (Cefas, 2016).

E.2.3 Today, the volume of seaweed production from Scotland is not specifically recorded in the FAO database. Previous estimates of seaweed production in Scotland indicated that approximately 5,000 tonnes per year of wild *A. nodosum* are harvested in Scotland, with unknown quantities of subtidal kelp and storm-cast seaweeds collected (James, 2010). Another estimate suggests approximately 5,500 tonnes of seaweed was harvested in the Outer Hebrides with small amounts also harvested (mainly for food and agriculture) in the Orkney and Shetlands Islands (Viking Fish Farms Ltd., 2012).

E.2.4 Seaweed cultivation in Scotland remains a nascent industry. It started with trials to investigate their potential use as a form of bioremediation at fish farms, namely the Calbha salmon farm site at Loch Duart on the north west coast in 2004 (Sanderson et al., 2012). The Scottish Association of Marine Science (SAMS) established trial sites in the Sound of Kerrera, Oban, in 2012 and a grid system based at Port a' Bhuiltin in 2014 (Stanley et al., 2019). Other small-scale cultivation in Scotland has taken place as far south as Loch Fyne and as far north as Lewis and Shetland (Stanley et al., 2019).

E.3 Current baseline

E.3.1 The following sections describe the current status of seaweed-based industry activity in Scotland with regard to the types of businesses involved, the range of processing undertaken, the species and products produced, and the industry's locational distribution. An estimate of the socio-economic value of the sector per product market is also presented (i.e. turnover, GVA and employment).

Definition of the seaweed-based industry

E.3.2 For the purposes of this report, the baseline evaluation has considered companies, community groups or other types of organisation whose core

business[55] relates to seaweed with regard to the harvesting, cultivation, processing and/or production of goods containing seaweed[56] within Scotland. Other actors within the seaweed-related industry, such as upstream supply chain companies providing equipment, or institutions/organisations involved in enterprise and R&D, are also described but are not considered quantitatively in the baseline.

Approach to characterising the current baseline

E.3.3 The information presented is based on publicly available information (e.g. from business websites; Companies House register; outputs of the Seaweed Review Steering Group) as well as information provided through consultation with seaweed-related businesses/organisations (n=12; note not all provided quantitative information) and wider stakeholders (n=10).

E.3.4 Seaweed-related businesses identified through searches and liaison with the Project Steering Group (PSG) were contacted via email and invited to engage with the study via a telephone interview[57]. This invitation was circulated by the Scottish Seaweed Industry Association (SSIA) to its members (n=27)[58] whilst

[55] A company or organisation's core business was considered to relate to seaweed if over 50% of their business or products related to seaweed/seaweed products (confirmed through consultation or judged from publicly available information).

[56] Where products containing seaweed comprise the majority of the products produced or sold.

[57] Note, three businesses identified at a relatively late stage in the process, for example during consultation, were not contacted directly. Hence information on those businesses was obtained through publicly available information.

[58] Although unable to provide company or organisation names under GDPR, the SSIA indicated that it had sent the invitation to engage with the study to 27 SSIA members, although they noted that not all members are active commercial entities (SSIA pers. comm.; 14 April 2020).

another 8 seaweed-related businesses and an additional 15 wider stakeholders identified by the project team were contacted through direct approach[59]. During interviews with businesses directly involved in the seaweed-based sector, information on the following was sought (see Appendix D for the full questionnaire):

- Type of products and proportion of business that relates to seaweed;
- Location of business;
- Location of markets;
- Type, source and volumes of raw material used;
- Processing of raw material and supply chain requirements;
- Current volume and value of activity (turnover);
- Operational and capital costs;
- Employment (number of FTE, skills shortage, location of the workforce);
- Constraints to current business;
- Future vision for the company, including identification of opportunities/new markets and any potential constraints, and vision for the sector as a whole in Scotland.

E.3.5 For the wider stakeholders, semi-structured telephone interviews were held, focussed on obtaining further information around their area of expertise or knowledge to further inform the analysis of the current status of the industry, future products, emerging market opportunities and growth potential.

E.3.6 A total of 22 interviews were conducted comprising seaweed-related businesses/organisations (n=12) and wider stakeholders (n=10). For confidentiality reasons these stakeholders are not listed in the report.

E.3.7 Whilst to the best of our knowledge the data presented captures most key seaweed-related businesses in Scotland, the General Data Protection

[59] Under GDPR the SSIA were not able to provide a list of members, hence where the project team thought that a business may not be a member, for example if a micro-business, these companies were approached directly by the project team via email.

Regulation and privacy issues meant obtaining an exhaustive list of seaweed-related businesses in Scotland, for example from CES or the industry association, was not possible. As such, it is likely that the data presented underestimate the scale of the sector, especially given the reported interest in the seaweed-based industry in Scotland and potential new entrants to the sector. Furthermore, it should be noted that for commercial confidentiality reasons, it has not been possible to provide disaggregated data for all sub-sectors of the industry, for example where 5 businesses or less are involved in the production of a specific product type.

E.3.8 Throughout the text, businesses are categorised by size using Companies House definitions which are shown in Table E1.

Table E1. Definition of company sizes

Company size and definitions
Micro-entities are those that meet at least two of: annual turnover of not more than £632,000; balance sheet total of not more than £316,000; and average number of employees must not be more than 10.
Small companies must meet at least two of: annual turnover of not more than £10.2 million; balance sheet total of not more than £5.1 million; and average number of employees must not be more than 50.
Medium-sized companies must meet at least two of: annual turnover of no more than £36 million; balance sheet total of not more than £18 million; and average number of employees must not be more than 250.
Any companies that do not meet the criteria for micro-entities, small or medium are **large companies**.

Source: Companies House (2019)

Overview of the current seaweed-based industry in Scotland

E.3.9 The vast majority of the current sector in Scotland utilises wild harvested seaweed sourced from Scottish waters, rather than cultivated seaweed. Therefore, the baseline text is necessarily focussed on these businesses, describing the type of businesses, supply chains, seaweed species used and

products. The emerging industry activity related to cultivating seaweed is then described separately.

Businesses and supply chains – wild seaweed harvesting

E.3.10 Of the nine seaweed-related businesses involved in harvesting and/or processing of wild seaweeds in Scotland (for which information was sourced), seven are classed as micro-entities and two are classed as small companies as per Companies House (2019) definitions (Table E1).

E.3.11 The majority of micro-entities operate at a small-scale, harvesting wild seaweed by hand. Most of these businesses can be considered as artisanal operations, harvesting small amounts (up to a tonne of seaweed per annum) where the production process (harvesting, processing, production, and packaging) is done entirely in-house. In general, equipment requirements are low-tech (e.g. air-drying racks, drying ovens, mills, sieves and packaging material). Packaging, labelling and delivery logistics are also requirements. A generic schematic representation of the production and supply chain for these types of businesses is shown is Figure E1.

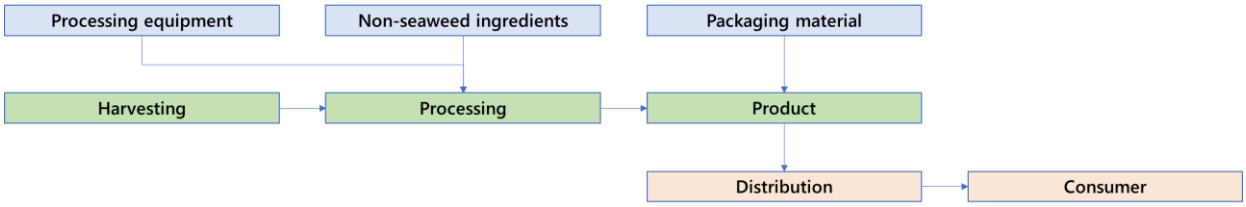

Figure E1. Generic supply chain model for micro-sized seaweed harvesting businesses in Scotland with in-house production – green = internal operations, blue = upstream supply chain (mostly outwith Scotland), red = downstream supply chain

E.3.12 Some of the micro-entities harvest or process slightly larger quantities of seaweed (up to 50 tonnes per annum) and also employ the use of external businesses in the manufacture and packaging of their products (Figure E2). One company has more than one seaweed supplier, including one outwith Scotland, to ensure a reliable (constant) supply of seaweed (i.e. to de-risk the supply chain which in general is considered under-developed due to lack of investment in Scotland).

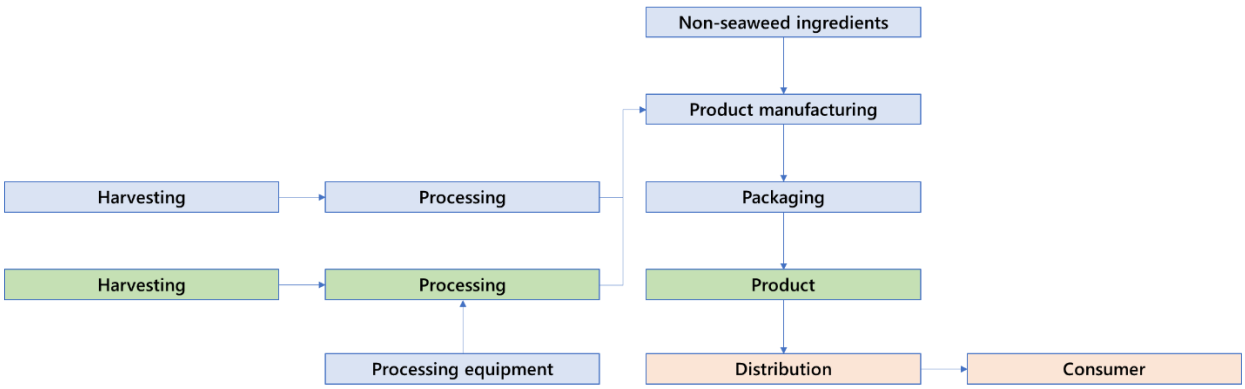

Figure E2. Generic supply chain model for micro-sized seaweed harvesting businesses in Scotland that outsource production – green = internal operations, blue = upstream supply chain (mostly outwith Scotland), red = downstream supply chain

E.3.13 The companies defined as small by Companies House definitions, operate at a relatively large scale compared with the micro-entities, whereby seaweed is harvested mechanically (using a specially modified vessel with cutter) and/or by hand (sometimes with the use of a rake and vessel). These businesses harvest larger volumes of seaweed (over a thousand tonnes per annum) which are processed by drying and milling to individual end-user specifications which can be used directly or are subsequently sold to supply other companies that make seaweed-based products (depending on the application). A generic schematic representation of the production and supply chain for these types of businesses is shown in Figure E3.

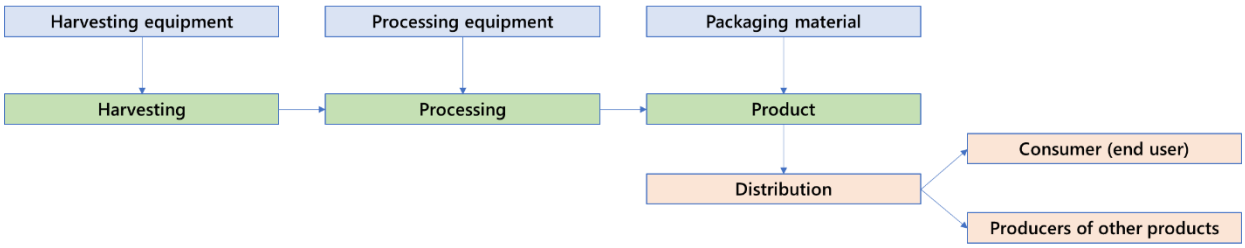

Figure E3. Generic supply chain model for small-sized seaweed harvesting businesses in Scotland – green = internal operations, blue = up-stream supply chain (mostly outwith Scotland), red = downstream supply chain

Seaweed species and product markets

E.3.14 The species harvested in the greatest quantity in Scotland is *A. nodosum* (egg wrack), which is harvested both by hand and mechanically from the intertidal area.

E.3.15 *A. nodosum* is processed for direct use as animal feed and soil conditioners, as well as being used to produce liquid seaweed fertiliser extracts. It is also processed to customer specifications to supply other companies with *A. nodosum* for the production of human food products, and bioactives within the nutraceuticals and cosmetics industries.

E.3.16 Many of the micro-entities in Scotland tend to hand harvest a diverse range of intertidal seaweed species, including kelps, wracks, red and green seaweeds. Of these species the kelps *L. digitata* (oarweed), *S. latissima* (sugar kelp) and the red seaweed *P. palmata* (dulse) comprise the largest proportion of the total harvest. The uses and products produced in Scotland from these species include human foods and cosmetic products containing seaweed material. Aside from where seaweed is harvested and sold fresh (in one instance), these types of products are considered higher value 'speciality' seaweed products (see Figure 14 in Cefas, 2016).

E.3.17 The range of seaweed species harvested, the method of harvest and the maximum allowable harvest tonnage under Crown Estate Scotland licence[60] are shown in Table E2. It should be noted that the maximum CES licensed harvest tonnages provided here only represent volumes of seaweed taken from CES-owned foreshore (i.e. approximately 50% of foreshore in Scotland) and are only stipulated for licensees where they intend to harvest larger amounts (i.e. 10's or 100's of tonnes per annum and above). The maximum licensed tonnages are based on stock and sustainable harvest assessments supplied by the licensee. It therefore does not necessarily represent actual harvested volumes and does not account for species harvested on private land not owned by CES, or for species harvested on smaller scales.

E.3.18 The seaweed 'activity mapping' exercise undertaken by the Seaweed Review Group in 2019 indicated that, at that time, there were 13 locations in Scotland in which wild seaweed harvesting was undertaken for commercial purposes. At nine of these locations landownership falls in some areas to the CES and in others to private landlords. A further four areas are solely under private landownership. The mapping exercise indicated that a total of up to 15,000 tonnes of seaweed was consented for harvest (per annum) under CES licence. The volume of seaweed harvested from privately owned land is not reported and hence not known.

E.3.19 Whilst information on the actual volume of seaweed harvested per business was sought during the consultation exercise in this study, this information was not always provided (especially where a large range of species are being harvested bit also due to commercial confidentiality), and not all businesses contacted engaged with the consultation. However, the outputs of the

[60] Harvesting seaweed from the foreshore or seabed (i.e. below mean low water springs) managed by Crown Estate Scotland (CES), for commercial reward, requires a licence to be obtained from CES (hereafter referred to as the CES seaweed harvesting licence). Where the foreshore is owned by a landowner other than the Crown, the landowners permission is required.

consultation (undertaken between February and May 2020) suggested that, at that time, businesses were not harvesting wild seaweed at the maximum volumes allowed under the CES licence. Based on information provided during the consultation it was estimated that in 2020, approximately 8,000 tonnes of wild seaweed was harvested (approximately 50% of the maximum allowed tonnage under CES licence) although it is acknowledged this is likely to be an underestimate for the reasons stated above and operations potentially being constrained in 2020 by COVID-19 restrictions..

E.3.20 The majority of seaweed-related businesses identified in this study sell their products mainly to retailers, and direct to consumers (e.g. cafes, restaurants, markets, or via online or shop sales). These are primarily within the locale of the business in Scotland, or otherwise within the UK. A few of the larger businesses also sell products to processors and wholesalers, sometimes via distributors, in the UK as well as internationally such as in Europe, the Middle East, and United States of America (USA).

Table E2. Species, method and maximum volumes of seaweed harvest under CES licence per annum in Scotland and seaweed product categories based on the consultation undertaken as part of this study (n=9)

Species	Harvest method	Maximum harvest tonnages under CES licence (tonnes) *	Product category
Ascophyllum nodosum (egg wrack)	Hand (including rake and nets from vessel) Mechanical using modified vessel	11,520.11	Horticulture Animal feed Bioactives (cosmetics, nutraceuticals) Human food
Fucus vesiculosus (bladder wrack)	Hand	249.47	Human food Bioactives (cosmetics, nutraceuticals)
Fucus serratus (serrated wrack)	Hand	200.65	Human food Bioactives (cosmetics)
Himanthalia elongata (thong weed)	Hand	101.46	Human food
Laminaria digitata (oarweed)	Hand	413.16	Human food Bioactives (cosmetics)
Laminaria hyperborea (tangle / cuvie)	Hand	50.94	Human food
Saccharina latissima (Sugar kelp)	Hand	9.76	Human food
Alaria esculenta (dabberlocks)	Hand	61.72	Human food
Porphyra sp. (laver species)	Hand	9.80	Human food

Species	Harvest method	Maximum harvest tonnages under CES licence (tonnes) *	Product category
Palmaria palmata (Dulse)	Hand	55.98	Human food Bioactives (cosmetics)
Osmundea pinnatifida (Pepper dulse)	Hand	2.17	Human food
Chondrus crispus / *Mastocarpus stellatus* (Carrageen)	Hand	8.14	Human food Bioactives (cosmetics)
Ulva sp.	Hand	8.24	Human food Bioactives (cosmetics)

Maximum consented harvest volume per species under Crown Estate Scotland licence was provided by CES. It does not account for species harvested on private land not managed by CES, for which the volumes harvested are not known.

Note: The CES licensed harvest tonnages only represent the consented maximum volumes of seaweed to be taken from CES-owned foreshore (i.e. approximately 50% of foreshore in Scotland). Such licences are only required for licensees who intend to harvest tens or hundreds of tonnes of seaweed per annum and the maximum licensed tonnages are based on stock and sustainable harvest assessments supplied by the licensee (Appendix A). The tonnages presented therefore do not necessarily represent actual harvested volumes and do not account for species harvested on private land not owned by CES, or species harvested at smaller scales. Whilst information on the volume of seaweed harvested per business was sought during consultation for this study, volumes per species were not always provided and thus are not presented here. Furthermore, not all seaweed-related businesses that operate in Scotland were able to input into the study.

Source: Data provided by Crown Estate Scotland (May, 2020) and stakeholder consultation

Current seaweed cultivation activity in Scotland

E.3.21 At the time of the consultation (February to May 2020), there was only one company commercially cultivating seaweed in Scotland. No information regarding the species cultivated or the tonnage harvested was available. The farm is owned by a vertically-integrated company that acts as the producer organisation, intermediary and end-user selling products for human consumption (Stanley et al., 2019).

E.3.22 There are also two experimental seaweed farms off the west coast of Scotland (the Cutter's Rock farm in the Sound of Kerrera and the Port A'Bhuiltin in the Forth of Lorne between the mainland and the island of Lismore) managed by the Scottish Association of Marine Science (SAMS). The Cutter's Rock farm is the smaller of the two farms, comprising of a total 60m of double longlines (set up similar to a mussel farm). The site at Port A'Bhuiltin is 30 hectare in total, currently with a single 100 x 100 m grid system for growing of seaweed and pre-permission in place for another gird system. It should be noted that although the site is 30 hectare in size, not all of this area is suitable for cultivation due in part to the seafloor structure. The main species cultivated currently are *Alaria esculenta*, *Saccharina latissima* and *Laminaria digitata*. Biomass harvested from the Port A'Bhuiltin farm in excess of that utilised for R&D may be available to feed into the current supply chain. Information on the tonnages currently harvested were not available for confidentiality reasons.

E.3.23 Hence, some seaweed cultivated in Scotland is currently being used within the supply chain in Scotland, albeit in low volumes (no specific information on tonnages was obtained due to commercial sensitivities). Information obtained through consultation indicated that there are companies in the seaweed value chain in Scotland who are keen to utilise seaweed cultivated in Scotland in their products. Currently the high cost of cultivated seaweed (compared to wild harvested seaweed) does not make this economically feasible, although the higher cost could potentially be acceptable if cultivated seaweed only comprised a small proportion of the overall volume of raw material needed (e.g. enabling the business to indicate that the product contained some seaweed farmed in Scotland). However, these supply chain businesses are currently

able to source seaweed from the global market (i.e. outwith Scotland) and hence are neither impacted by the lack of Scottish cultivated seaweed nor currently directly driving the demand for cultivated seaweed in Scotland (Stanley et al. 2019).

E.3.24 In general, information regarding potential seaweed cultivation activity 'in the pipeline' is not in the public domain and therefore cannot be disclosed. However, information obtained through consultation indicated that there were a number (< 10) of marine licence applications for seaweed farms around Scotland currently in process[61].

E.3.25 The recent seaweed farming feasibility study undertaken for Argyll and Bute Council (Stanley et al., 2019) indicated that there are several companies that currently harvest wild seaweed that are interested in transitioning to cultivating seaweed. Consultation undertaken for this study (not exclusively with businesses currently wild harvesting seaweed) supported this to an extent. Three companies expressed an intention to cultivate seaweed, four had no current plans to cultivate seaweed although they would potentially be interested in the future if it was economically viable or higher value species could be farmed, whilst four companies did not express an intention to cultivate seaweed in the future. Some companies indicated that they had previously set up or been involved in R&D trials for seaweed cultivation but as cultivation was not currently economically viable, their focus in the immediate future was on product and market expansion or development from wild harvested seaweed. The primary species of interest to cultivate in the immediate future was *S. latissima*, *A. esculenta* (both of interest for the food market) and *L. digitata*.

E.3.26 Other seaweed species that stakeholders expressed an interest in being able to cultivate included green seaweed species (e.g. *Ulva lactuca*, *Ulva linza* and

[61] Data supplied by Marine Scotland Licensing Operations team on 26.04.21 showed that there are now nine licensed seaweed farming sites and another six marine licence applications of seaweed farms being processed. However, it is not known how many of these farms are currently operational.

Undaria pinnatifida) and higher value the red seaweeds such as *P. palmata, Osmundea pinnatifida, Chondrus crispus, Gracilaria spp. (G. gracilis), Gelidium* and *Gracilariopsis longissimi*, although such species would likely need to be cultivated in tanks on land. Whilst such red seaweed species are considered high value species and would only be required to be cultivated in small volumes (e.g. for use within the cosmetics industry) tank-based cultivation has high energy demands (for example to maintain specific temperatures or constant bubbling (tumble culture), requiring these costs to be offset.

E.3.27 The industry's and wider stakeholder opinions on the key drivers and constraints to developing the seaweed farming sub-sector in Scotland are presented in Section 5 of the main report.

Distribution of seaweed-based businesses in Scotland

E.3.28 The majority of seaweed-based businesses, which harvest seaweed, or currently utilise wild harvested seaweed are located on the west coast of Scotland (primarily within the Local Authority areas of Comhairle nan Eilean Siar and Argyll and Bute, but also the west coast of the Highlands) (Table E3). A lesser number of businesses are based on the east coast (within the Highlands and Fife), whilst one is based outwith Scotland (in England).

E.3.29 The majority of businesses that harvest seaweed do so within the same locale in which seaweed is processed and/or their business is located. However, a few harvest or source seaweed outwith the immediate locale in which they are based; this includes harvesting taking place in the Western Isles and Orkney. A few businesses that rely on specialist supply chain companies to manufacture or package finished seaweed products also use other businesses located outside of Scotland (see Figure E2).

Table E3. Location of businesses using seaweed wild harvested in Scotland

Local Authority Area	Number of businesses
Argyll and Bute	4
Comhairle nan Eilean Siar	5
The Highlands	2
Fife	1
England	1
NB: This table shows the location of businesses that use seaweed wild harvested in Scotland as opposed to where seaweed is harvested (though in the majority of cases these are within the same locale for each business).	

E.3.30 The one established seaweed farm in Scotland, at the time of consultation (2020), is based within the Local Authority area of Argyll and Bute. Most of the seaweed cultivation activity in the pipeline (i.e. currently seeking consents) would predominately be located off the west coast of Scotland (given the more sheltered nature of the coastline) although there is also interest off the east coast (wider stakeholder input).

Other actors in Scotland

E.3.31 A wide range of other organisations are also involved in supporting and developing the seaweed-industry in Scotland, although their core business does not relate to seaweed as per the definition presented above. Such actors are involved in R&D (e.g. SAMS, The James Hutton Institute, North Atlantic Fisheries College), Innovation (e.g. SAMS, IBiolC, Scottish Aquaculture Innovation Centre (SAIC)) and Enterprise (e.g. Highlands and Island Enterprise, Scottish Enterprise) (see Stanley et al. 2019). Whilst a monetary value of such actors has not been incorporated into the economic evaluation of the current seaweed-based sector in Scotland (presented in Section E.4 below), where information was obtained from such stakeholders during the consultation it has been incorporated into the review of the current status of the seaweed-based industry in Scotland (above) and in the development of plausible scenarios for the seaweed-based sector in Scotland (see Section 6 in main report).

E.4 Current baseline – economic analysis

E.4.1 The economic analysis is divided into the following aspects:

- Scale and viability of existing companies, including turnover, profit and projected growth;
- GVA based on difference between turnover and operational costs;
- Employment based on full-time equivalents currently employed;

E.4.2 The economic analysis is presented by product grouping where possible (e.g. food for human consumption, animal feed, horticultural products, bioactive products for the cosmeceutical and pharmaceutical industries, and innovative applications or biotechnology). However, in some cases, it is not possible to report monetary estimates by product group due to confidentiality issues arising when there are a small number of companies involved. Where this is the case, quantitative data for that specific product group is not presented and a more aggregated summary is given, combining more than one product group to protect confidentiality. A small number of additional companies involved in seaweed harvesting and/or cultivation that were not interviewed were identified during our data search, but information on these companies (e.g. from Companies House) was very limited. Hence it is known that some companies who generate turnover from seaweed have not been captured within this analysis (for example, if they did not engage, did not provide quantitative information and/or no information was available on Companies House), and as such the estimated turnover and GVA are likely to be an under-estimate and should be regarded as indicative.

E.4.3 It should also be noted that any businesses which are not yet trading commercially were not considered in the current economic analysis other than for enabling the number of businesses per product group to be estimated (see below), although their potential value and growth potential were considered in the projected future scenarios (Section 6 main report).

Scale and viability of existing companies

E.4.4 The scale of the current market is based on the number of companies operating in a product category, turnover, profit and growth over the past three years. Growth potential is also considered, as reported by companies during the interviews or taken from information submitted to Companies House. The results are provided in Table E4.

E.4.5 Nine companies were identified that are producing **human food**. The economic baseline is based on nine companies, all of which are identified as being micro-entities or small companies under the Companies House (2019) definitions (see Table E1). Five companies only produce human food, while four others also produce other product types.

Table E4 Scale of markets by product type

Product category	No. of companies[1]	Turnover		Profit		Growth
		Mean	Median	Mean	Median	
Human food	9	£210,000	£190,000	£34,000 (but some companies report losses)	£21,000	↑
Animal feed	2	Confidential		Confidential		→
Horticulture	2	Confidential		Confidential		↗
Bioactives (cosmetics, pharmaceuticals, and nutraceuticals)	7	£87,000	£125,000	£15,000	£13,000	↑
Hydrocolloids	None in Scotland	-		-		-
Biofuels	None identified	-		-		-
Innovative/ biotechnology	2	Not applicable		Not applicable		↑

Key: ↑	Growth reported to at least double in next few years
↗	Growth expected but to be less than double in next few years
→	Little or no growth expected, expected to remain more or less at the same level
↘	Potential reduction in production expected

Notes:

[1] Companies producing more than one product category are counted for each category. Thus the total number of companies recorded in the table exceeds the total number of producers identified: 13. Turnover has been allocated to the different product categories to avoid double counting. Number of companies includes both those interviewed and those identified as producing seaweed-based products based on publicly available information. Note information on turnover and/or GVA was not available for all of these companies, hence, total turnover is likely to be an under-estimate

E.4.6 There are seven companies producing **bioactives**. Of these, three produce cosmetics, three produce nutraceuticals and one produces both cosmetics and nutraceuticals. Four of these companies also produce human food. As with human food, all of these companies are micro-entities or small companies.

E.4.7 **For horticulture** and **animal feed**, there were two companies that reported producing these products, both of which are relatively large-scale harvesters and processors. As there are only two companies identified for these products, no quantitative data is presented for this category to protect commercial confidentiality.

E.4.8 Turnover varies by type of product but is also highly variable within any one product category. Average (mean) turnover for companies involved in production of **human food** is around £210,000 per year (median £191,000)[62]. Average (mean) profits reported are around £34,000 per year (median £21,000)[63]. Some companies reported losses (which have been excluded from the mean profits) for example due to investment in equipment.

E.4.9 For **bioactives**, average (mean) turnover is estimated at £87,000 per year (median £125,000)[64] with profits estimated at £15,000 per year (median £13,000)[65]. None of the companies reported losses.

[62] Based on reported and estimated turnover from 6 companies (estimated turnover includes where product value and tonnage was given). The two companies that did not provide turnover data (or had no turnover in the case of the start-up) are not counted in the mean value.

[63] Based on reported or estimated profits from 4 companies (estimated profits per product category are based on an assumed turnover by product category, with profit then taken as the same percentage as for the overall company information).

[64] Based on reported and estimated turnover from 4 companies. No additional information product value or tonnage was provided so turnover for the remaining companies cannot be estimated.

[65] Based on reported or estimated profits from 3 companies (approach to estimated profits as for human food)

E.4.10 For innovative products and **biotechnology**, there is some development that is on-going both through start-ups. These businesses are at an early stage so no turnover or profit information is available.

Gross Value Added

E.4.11 Overall turnover across all companies where data are available (or can be estimated) is around £4 million with an average (mean) turnover of £500,000 and a median of £270,000 per company[66]. Gross Value Added (GVA) can be extrapolated across the remaining companies, based on average GVA for small-scale, medium-scale and large-scale companies[67] but ignoring start-ups as these are not currently generating any GVA.

E.4.12 **Total GVA from the seaweed industry in Scotland** can then be estimated at £510,000 per year, with this based on weighted average GVA of 13% of turnover. This is expected to be an under-estimate as some companies producing seaweed-based products may not be captured and turnover data was not available for all due to gaps in both the information provided via interviews and from publicly available data such as from Companies House. This compares with GVA in Scotland (for 2018) of £485 million for fishing and aquaculture, £1,609 million for manufacture of food products and £1,036 million for manufacture of pharmaceutical products (ONS, 2019).

[66] Based on reported (and estimated) data for 8 companies (note this excludes start-ups). Turnover ranges from less than £10,000 per year to more than £1 million per year, hence the large difference between the mean and the median. The number of companies included in the analysis is 8 as this includes some companies producing more than one product type (hence the number is not the sum of the companies across the human food, bioactives, animal feed and horticulture product types)

[67] Extrapolated based on 25% GVA from turnover for small-scale, 20% GVA from turnover for medium-scale and 10% from turnover for large-scale companies.

Employment

E.4.13 Ten of the companies responding to the survey reported the number of employees. This gives a total of 59 employees, with an average (mean) of 7 per company and median of 4 employees. There is a significant range with some companies having no staff other than the owners, up to a maximum of 20.

E.4.14 Based on 59 employees, **GVA per FTE can be estimated at £8,600 per FTE**. This compares with the following GVA per head for the local authority areas in which the seaweed businesses are currently operating (data for 2017) (ONS, 2018):

- Lochaber, Skye and Lochalsh, Arran and Cumbrae and Argyll and Bute: £25,025 per head
- Na h-Eilean Siar: £19,694 per head
- Orkney Islands: £23,752 per head
- Clackmannanshire and Fife: £21,165 per head
- Revenue per FTE (estimated as turnover ÷ number of FTEs) is around £68,000.

E.5 References

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F Economic Analysis Methodology and Key Results

F.1 Introduction

F.1.1 This appendix sets out the methodology employed to estimate the impacts of the Scottish seaweed industry on the Scottish economy, in terms of business turnover, its economic impact as measured by Gross Value Added (GVA) and employment impacts as measured by full-time equivalents (FTE). Firstly, it will present the key definitions, before outlining key assumptions and methodological steps for turnover estimates. Following this, assumptions used in the GVA and employment analysis will be set out, followed by the methodology for assessing the wider impacts of the seaweed industry in terms of future projected economic growth (GVA) and employment impacts under each scenario (the Business as Usual (BAU) scenario and the higher growth scenario). Furthermore, it will provide key assumptions made around the Scottish economy and two illustrative communities.

F.2 Definitions

F.2.1 Throughout this report, reference will be made to direct, indirect, induced effects and total effects which are defined as follows:

- Direct effect: When there is an increase in final demand for a product, the equivalent increase in output to meet this final demand is referred to as the direct effect;
- Indirect effect: To meet the increase in final demand for a product, firms will need resources and services from their supply chains; the increase in output for firms along the supply chain to meet this demand is referred to as the indirect effect;
- Induced effect: The increase in turnover from both the direct and indirect effects will subsequently lead to an increase in the level of household income because of the effect on wages, a proportion of which will be re-

spent on domestically produced products which is referred to as the induced effect; and

- Total effect: Total effects represent the total impact on the economy, and comprise of direct, indirect and induced effects.

F.3 Assumptions and multipliers for turnover effect estimates

F.3.1 To estimate the impacts on turnover, the following assumptions have been made:

- Before applying the input-output multipliers to the projected growth of the industry, growth has been adjusted for taxes less subsidies on products[68].
- In order to match the increased demand under both the BAU and higher growth scenarios, it is necessary to make some assumptions around the value of seaweed per tonne. Since this is not available for Scotland, the value of Irish seaweed production is used as a proxy. The value of Irish harvested seaweed is estimated to be worth EUR 135[69] or £120 per tonne[70]. This is a simplification that assumes an average value across all species; in reality, it is expected that there would be variation in price by species. Additionally, given that most businesses in the seaweed industry in Scotland are vertically integrated it has been assumed that any additional value obtained from higher value seaweed is captured within the turnover of high value products. In particular, this assumption applies to the higher value of cultivated seaweed (likely a higher price than

[68] Projected turnover reduced by 3%, based on latest 2017 figures in the Scottish Government Input-Output Tables 1998 – 2017, published September 2020.

[69] Based on 29,500 tonnes harvested per year based on FAO (2018; 2019), Cefas (2019) and Norton et al. (2014 estimating a value of seaweed production output in Ireland at 4 million euros per year).

[70] Based on exchange rates of Euro to Pound Sterling of 1€ = £0.89 on 12/11/2020.

harvested seaweed, for example, see Crown Estate Scotland (2021)). As such, it is possible that some of the value could be underestimated if excess cultivated seaweed is sold to other businesses. However, given the projected scenarios, this is deemed to be unlikely.

- It is assumed that current seaweed production from wild harvesting in Scotland is 8,000 tonnes per year. It is assumed that the maximum consented tonnage (under CES licence) will increase to 30,000 tonnes per year by 2040.
- It is assumed that there is spare capacity in the economy to meet the extra demand;
- It is assumed that newly created economic activity is entirely additional, that it does not replace other activity.

F.3.2 There are currently no available input-output multipliers for seaweed production in Scotland. As such, multipliers have been developed based on input from consultation and a literature review of similar industries. It should be noted that these multipliers should be treated as indicative estimates, erring on the side of caution. They are described as follows:

Output multiplier for seaweed production from wild harvesting

F.3.3 As a conservative estimate, the multiplier which has been used for seaweed production from the wild harvesting sector is 1.17. This is based on a study on the Welsh cockle industry (used as a proxy for a relatively small-scale industry with a limited supply chain), which developed a specific multiplier, based on information from stakeholder interviews, direct observation, secondary data, and production and price data. This multiplier has been used as a conservative estimate for seaweed production from wild harvesting under the BAU and higher growth scenario.

Output multiplier for seaweed cultivation

F.3.4 The multiplier for seaweed cultivation has been derived from input-output multipliers for fishing, and for aquaculture. These have been adapted to reflect

the strongest sectoral linkages, based on the supply chain analysis conducted as part of the scenarios. Moreover, they have been adjusted to account for linkages that may be more developed in the future. Table F1 sets out the inputs which have been used to develop the multiplier.

Table F1 Multiplier for seaweed cultivation for the higher growth scenario

Sector	Direct and indirect effect by industry group	Notes
Seaweed	1000	Conservative estimate
Electrical equipment	2.2	Based on the average input of electrical equipment for fishing and aquaculture
Repair and maintenance	24.7	Based on the average input of repair and maintenance services for fishing and aquaculture
Wholesale – excluding vehicles	30.2	Based on wholesale (excluding vehicles) for the fishing sector
Other land transport	14.9	Based on the average input of other land transport for fishing and aquaculture
Water transport	0.5	Based on the average input of water transport for fishing and aquaculture
Food & Beverage services	2.3	Based on food and beverage services for the aquaculture sector
Financial services	17.7	Based on the average input of financial services for fishing and aquaculture
Total	1092.48	
Adjustment factor	1.30821	Adjustment factor to account for linkages that may become more developed over the period 2021-2040 and other sectoral linkages unaccounted for above (as based on similar sectors) . Calculated as the average difference between Type 1 multipliers for fishing and aquaculture, and adjusted Type 1 multipliers for fishing and aquaculture

Sector	Direct and indirect effect by industry group	Notes
Seaweed cultivation multiplier	1.429	

Output multiplier for seaweed-based products

F.3.5 For the purpose of assessing the impacts on businesses who produce seaweed-based products and their associated supply chains, three multipliers have been developed. Since there are no seaweed-based product multipliers available in Scotland, the input-output multipliers from other, similar, industries have been used. These have been adjusted to account for only the inputs which are relevant to the seaweed industry.

F.3.6 The analysis is broken down into three product categories, which are human food products, bioactives, and all other seaweed-based products. The multipliers which have been developed use fish and fruit processing, pharmaceuticals, and agrochemicals, respectively, as a starting point. The multipliers have been adjusted, by removing the primary inputs as well as removing inputs which are not relevant for the seaweed industry. The inputs which have been used are:

- Manufacturing inputs: Fabricated metal, electrical equipment, computers and electronics, machinery and equipment, rubber and plastic, repair and maintenance;
- Utilities: Electricity, gas, water and sewerage, waste management;
- Construction;
- Wholesale and retail: Wholesale (excluding vehicles) and retail (excluding vehicles);
- Transport: Rail transport, water transport, air transport, other land transport, support services for transport, other transport equipment, Post & Courier;
- Financial: Financial services, insurance and pensions; and

- Professional services and administration: Business support services, employment services, legal activities, accounting and tax services, other professional services, research and development, advertising and market research, rental and leasing services, public administration and defence.

F.3.7 Table F2 provides a breakdown of the multiplier by input and product type[71]:

Table F2 Direct and indirect effects for each product category by input type

Sector	Human food products	Bioactive products	All other products
Own industry	1000	1000	1000
Manufacturing	26.97	6.14	6.75
Utilities	44.28	13.65	100.93
Construction	11.83	2.46	6.32
Wholesale and retail	106.32	15.39	46.47
Transport	41.02	9.21	29.56
Financial	24.97	13.58	21.18
Information and communication	4.21	2.79	3.20
Professional services and administration	25.45	12.59	12.90
Total	**1,285**	**1,075**	**1,227**

[71] Whilst the multipliers have been adjusted for primary inputs, the adjustment factor for other sectoral linkages has not been applied because it is already captured through the cultivation sector (as explained above).

F.4 Methodological steps for applying output multipliers

F.4.1 The process of applying the output multipliers set out in Appendix subsection F.3 to estimate direct, indirect and total turnover is as follows:

1. Adjust estimated turnover by taxes less subsidies to obtain direct effect;
2. Apply output multiplier to turnover (for production and each product separately) as projected under the scenarios to estimate the economic impact of the industry and its supply chain (total effect); and
3. Subtract direct effect from total effect to estimate indirect effect.

F.5 Assumptions for GVA and employment estimates

F.5.1 The results of this analysis are based on projected scenarios which inherently give rise to a number of uncertainties because they are estimating impacts in the future. Moreover, given the emergent nature of the industry there is a sizable gap in industry specific data. As such, a number of assumptions have been made to enable the analysis of GVA and employment.

F.5.2 There are currently no published Scottish seaweed GVA effect or employment effect multipliers available. As such, this analysis has used multipliers from other, similar, industries in Scotland as a best available proxy to estimate the impacts that the Scottish seaweed industry may have upon the economy. The specific effect multipliers which have been used are set out as follows:

- The aquaculture GVA effect and employment effect multipliers have been used to estimate the impacts of seaweed production (wild harvested only under BAU and wild harvested and cultivated under the higher growth scenario);
- The fish and fruit processing GVA effect and employment effect multipliers have been used to estimate the impacts of seaweed food products for human consumption;
- The pharmaceutical GVA effect and employment effect multipliers have been used to estimate the impacts of bioactive products; and

- The Inorganic chemicals, dyestuffs and agrochemicals GVA and employment effect multipliers have been used to estimate the impact of all other seaweed-based products.

F.5.3 Moreover, the following assumptions have been made to enable the modelling of economic impacts:

- Turnover adjusted for taxes less subsidies is assumed to represent final demand for the industry;
- It is assumed that there is spare capacity in the economy to meet the extra demand;
- It is assumed that newly created economic activity is entirely additional, that is it does not replace other activity

F.6 Methodological steps for applying effect multipliers

F.6.1 This subsection sets out the methodology used to estimate the economic impact of the Scottish seaweed industry. The economic impact on the economy is measured by estimated GVA, whilst the impact on employment is measured as the maximum number of FTE that are estimated to be created by the industry.

F.6.2 The specific multipliers which have been used are set out in Table F3 (see assumptions in Section F5).

Table F3 GVA effect and employment effect multipliers

Subsector	GVA effect		Employment effect	
	Type 1	Type 2	Type 1	Type 2
Seaweed production	0.57	0.64	7.30	8.26
Seaweed food products	0.53	0.63	9.84	11.20
Bioactive products	0.86	1.00	3.88	5.87
Other products	0.61	0.73	6.36	7.95

F.6.3 The process of applying the effect multipliers set out in Table F3 to estimate total GVA and FTE supported by the Scottish seaweed industry is described as follows:

- Adjust estimated turnover by taxes less subsidies;
- Apply GVA effect type 1 multiplier to estimated turnover as projected under the scenarios to estimate the direct and indirect economic impact of the industry and its supply chain;
- Apply GVA effect type 2 multiplier to estimated turnover as projected under the scenarios to estimate the direct, indirect and induced economic impact of the industry and its supply chain;
- Subtract the resulting impact of GVA effect type 1 multipliers from the resulting impact of GVA effect type 2 multipliers to estimate the induced effect of the seaweed industry;
- Apply employment effect type 1 multipliers to estimated turnover as projected under the scenarios to estimate the impact on jobs within the industry and its supply chain;
- Apply employment effect type 2 multipliers to estimated turnover as projected under the scenarios; and
- Subtract FTE arising from employment effect type 1 from FTE arising from employment effect type 2 to estimate the induced number of FTE.

F.7 Results under the BAU and Higher Growth Scenarios

F.7.1 This subsection sets out the key results from applying the process described in the previous subsection on the Scottish seaweed industry. Full results are presented within the calculation tables presented in Appendix G.

BAU key findings

F.7.2 The results presented here reflect the projected evolution of the Scottish seaweed industry under the BAU scenario in terms of GVA impact and the number of FTE jobs supported. Table F4 below reports the findings:

Table F4 GVA and employment impacts under BAU scenario

	2021	2030	2040
GVA type 1 (Direct and Indirect)	£3.6 million	£7.8 million	£11.5 million
GVA type 2 (Induced)	£0.6 million	£1.3 million	£1.9 million
GVA Total Impact	£4.2 million	£9.1 million	£13.4 million
Employment Type 1 (Direct and Indirect)	40	90	130
Employment Type 2 (Induced)	10	20	30
Employment Total Impact	50	110	160
Rounding may lead to figures not summing exactly in some cases. GVA values are nominal values and are rounded to nearest £0.1 million, FTE rounded to nearest 10.			

Higher Growth Scenario

F.7.3 The results presented here reflect the projected evolution of the Scottish seaweed industry under the higher growth scenario in terms of GVA impact and the number of FTE jobs supported. Table F5 below reports the findings:

Table F5 GVA and employment impacts under higher growth scenario

	2021	2030	2040
GVA type 1 (Direct and Indirect)	£3.7 million	£13.8 million	£38.5 million
GVA type 2 (Induced)	£0.6 million	£2.4 million	£6.6 million
GVA Total Impact	£4.3 million	£16.2 million	£45.1 million
Employment Type 1 (Direct and Indirect)	40	160	400
Employment Type 2 (Induced)	10	30	90
Employment Total Impact	50	190	490
Rounding may lead to figures not summing exactly in some cases. GVA values are nominal values and are rounded to nearest £0.1 million, FTE rounded to nearest 10			

F.8 Impact on the Scottish Economy

F.8.1 The results from the previous subsection (F.6) set out the estimated impact of the Scottish seaweed industry in terms of economic contributing to GVA and the maximum number of jobs supported through the industry. This subsection presents those results in the context of the overall Scottish economy.

F.8.2 Before presenting the results, it is important to set out some assumptions made with regard to the economy in Scotland. Baseline statistics are set out in Table F6.

Table F6 Assumptions around the Scottish economy

Metric	Value	Assumption	Source
Working age population (2019)	3,497,800		Nomis (2019) Labour market profile – Scotland. Office of National Statistics. Accessed at Labour Market Profile - Nomis - Official Labour Market Statistics (nomisweb.co.uk)
Estimated change in working age population 2019 to 2040	-0.05%	NRS projections provide estimates for the period 2018-2038 (0.10%) and 2018-2043 (-0.20%). This value assumes the change for the period 2019-2040 is the average of the two.	NRS (2019) Projected Population of Scotland (2018-based). Accessed at Population Projections Scotland | National Records of Scotland (nrscotland.gov.uk)
Estimated working age population in 2040	3,496,051	Applies the estimate from above	
Proportion of working age population who are economically active in 2040	79%	Assumed the proportion of working age population who are economically active remains unchanged	Nomis (2019) Labour market profile – Scotland. Office of National Statistics. Accessed at Labour Market Profile - Nomis - Official Labour Market Statistics (nomisweb.co.uk)

Metric	Value	Assumption	Source
Estimated number of people who are economically active in 2040	2,768,615		
Unemployment rate in 2040	4.1%	Assumed the unemployment rate, as a % of those who are economically active, remains constant	Nomis (2019) Labour market profile – Scotland. Office of National Statistics. Accessed at Labour Market Profile - Nomis - Official Labour Market Statistics (nomisweb.co.uk)
Estimated number of unemployed in Scotland in 2040	113,943		
Estimated GVA in 2018	£143.32 billion		Statista (2020) Scotland: Gross value added from 2000-2018. Accessed at • Gross value added (GVA) in Scotland 2018 | Statista
Estimated GVA in 2040	£182.32 billion	Government estimates for growth of GVA for the period 2020 to 2030 are 1.1% annually. This is assumed to remain constant for the period 2018-2040	Harari, D. and Ward, M. (2021) Regional and country economic indicators. Briefing paper, number 06924. Accessed at Regional and National Economic Indicators - House of Commons Library (parliament.uk)
Rounding may lead to figures not summing exactly in some cases. GVA values rounded to nearest £0.1 million, FTE rounded to nearest 10			

F.8.3 Table F7 sets out the estimated impacts of the Scottish seaweed industry in 2040 in relation to the overall Scottish Economy.

Table F7 National impacts in 2040

Impact	BAU	Higher Growth
Estimated GVA in 2040	£182 billion	£182 billion
Seaweed GVA type 1 (direct and indirect) as a proportion of Scotland's GVA	0.0063%	0.0211%
Seaweed GVA type 2 (induced) as a proportion of Scotland's GVA	0.0011%	0.0036%
Total Seaweed GVA as a proportion of Scotland's GVA	0.0074%	0.0247%
Estimated number of unemployed in 2040	113,943	113,943
Estimated change in the number of unemployed from the Type 1 (direct and indirect) seaweed impacts	-0.11%	-0.35%
Estimated change in the number of unemployed from the Type 2 (induced) seaweed impacts	-0.02%	-0.08%
Estimated change in the number of unemployed as a result from total seaweed impacts	-0.14%	-0.43%

F.9 Impacts within illustrative communities

F.9.1 This subsection reports the results of the seaweed industry in the context of two distinct illustrative Scottish communities. The first is an Island community, whilst the second represents a mainland community (Table F8). This is intended to provide insight into the potential impacts on representative communities within Scotland. For the purpose of estimating impacts, it has been assumed that jobs are fully retained within the community. Naturally, the degree to which a given community would benefit from the seaweed industry would depend on the concentration of industry within that community and the extent to which jobs are retained locally. Moreover, it has been assumed for the purpose of estimation, that jobs are taken up by local people. However, the extent of impacts may differ in reality depending on whether migration is required to fulfil the jobs created by the industry.

Table F8 Statistics for two illustrative communities in 2040

Statistics	Island Community	Mainland Community
Population	23,000	74,000
Number of people who are economically active	12,000	34,000
Unemployment rate	2.8%	4.5%
Number of people of are unemployed	340	1500
Total GVA for community	£690 million	£1.7 billion
Rounding may lead to figures not summing exactly in some cases. GVA values rounded to nearest £0.1 million, FTE rounded to nearest 10		

Source: GOV.UK website

F.9.2 Having set out the general characteristics of these two communities, this subsection will now report the impact that the Scottish seaweed industry would have upon these communities if it were to develop and concentrate within the community over the period 2021 to 2040. Specifically, impacts are estimated with a concentration of 25% of the industry locating in each community. It should be noted that the actual impacts experienced within given communities will depend on the specific characteristics of a community and on the extent to which industry concentrates within each community.

Island community

F.9.3 The island community is an illustrative representation of an island community in Scotland with a relatively small population. Its remote nature would mean that connections to more developed areas of Scotland are likely to be less established than that of the mainland community. As such, it is likely to be experiencing greater economic and social challenges than the mainland community. The following Table F9 sets out estimated impacts of the Scottish seaweed industry in 2040 under the BAU and higher growth scenario. It should be noted that whilst these figures are presented for 2040, they represent the organic development of the industry across a 20 year period (i.e. the overall change to GVA or to employment would not take place all at once, but would increase over the period in line with the scenario projections). As such, they

should be treated as illustrative examples of what the economic outlook of the community may look like if the industry were to concentrate in the community in the form of a cluster under the different growth scenarios.

Table F9 Illustrative impacts for an island community in 2040 with an industry concentration of 25%

Impact	BAU	Higher Growth
Seaweed GVA type 1 (direct and indirect) as a % of the communities GVA	0.42%	1.4%
Seaweed GVA type 2 (induced) as a % of the communities GVA	0.07%	0.24%
Total seaweed GVA as a % of the communities GVA	0.49%	1.63%
Change in the number of unemployed when including the seaweed industry and its supply chain (Type 1, (direct and indirect)	-9.7%	-29.4%
Change in the number of unemployed arising from higher spending (Type 2, induced)	-2%	-6.9%
Total change in the number of unemployed (Type 1 + Type 2)	-11.8%	-36.3%
Rounding may lead to figures not summing exactly in some cases. GVA values rounded to nearest £0.1 million, FTE rounded to nearest 10		

Mainland community

F.9.4 The mainland community is an illustrative representation of a community located on the east coast of Scotland, with a relatively large population. It is located close to more developed areas of Scotland with good transport links to major hubs. It is likely to be experiencing more prosperous economic conditions than the island community. The following Table F10 sets out the estimated impacts of the Scottish seaweed industry in 2040 under the BAU and higher growth scenario. As per the island community, these figures are presented for 2040 to provide an illustration of the potential economic outlook if the seaweed industry were to concentrate in the community in the form of a cluster under the different growth scenarios. Whilst the impacts are presented for 2040, they represent the natural development of the industry across a 20 year period (i.e.

the overall change to GVA or to employment would not take place all at once, but would increase over the period in line with the scenario projections).

Table F10 Illustrative impacts for a mainland community in 2040 with an industry concentration of 25%

Impact	BAU	Higher Growth
Seaweed GVA type 1 (direct and indirect) as a % of the communities GVA	0.17%	0.56%
Seaweed GVA type 2 (induced) as a % of the communities GVA	0.03%	0.10%
Total seaweed GVA as a % of the communities GVA	0.20%	0.66%
Change in the number of unemployed when including the seaweed industry and its supply chain (Type 1, direct and indirect)	-2.1%	-6.4%
Change in the number of unemployed arising from higher spending (Type 2, induced)	0.4%	1.5%
Total change in the number of unemployed (Type 1 + Type 2)	2.6%	7.9%
Rounding may lead to figures not summing exactly in some cases. GVA values rounded to nearest £0.1 million, FTE rounded to nearest 10		

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G Calculation Tables

Table G1 Projected production (tonnes) of wild harvested and cultivated seaweed under the two scenarios

	2021	2025	2030	2035	2040
BAU					
Wild harvesting	8,000	10,164	13,711	18,495	24,948
Cultivation	0	0	0	0	0
Higher growth					
Wild harvesting	8,000	10,567	14,962	21,187	30,000
Cultivation	0	1,500	9,000	16,500	22,500

Table G2 Projected economic impact of seaweed production (wild harvesting only) under BAU scenario

BAU	2021	2025	2030	2035	2040
Turnover	£960,000	£1,219,723	£1,645,313	£2,219,401	£2,993,802
Adjustment for T - S	£28,800	£36,592	£49,359	£66,582	£89,814
Direct	£931,200	£1,183,131	£1,595,953	£2,152,819	£2,903,988
Output effect					
Indirect effect	£158,304	£201,132	£271,312	£365,979	£493,678
Total	£1,089,504	£1,384,263	£1,867,265	£2,518,798	£3,397,666
Type 1 GVA					
Total	£533,506	£677,844	£914,359	£1,233,400	£1,663,763
Type 2 GVA					
Induced total	£597,366	£758,980	£1,023,806	£1,381,036	£1,862,912
Induced effect	£63,860	£81,136	£109,447	£147,635	£199,149
Type 1 employment effect					
Effect	6,794,270	8,632,422	11,644,477	15,707,509	21,188,229
FTE	7	9	12	16	21
Type 2 employment effect					
Effect	7,694,497.46	9,776,201.01	13,187,347.48	17,788,723.18	23,995,627.09
FTE	8	10	13	18	24
Induced FTE	1	1	2	2	3

Table G3 Projected economic impact of seaweed production (wild harvesting) under the higher growth scenario

Higher growth	2021	2025	2030	2035	2040
Turnover	£960,000	£1,268,002	£1,795,481	£2,542,387	£3,600,000
Adjustment for T - S	£28,800	£38,040	£53,864	£76,272	£108,000
Direct	£931,200	£1,229,962	£1,741,616	£2,466,115	£3,492,000
Output effect					
Indirect effect	£158,304	£209,094	£296,075	£419,240	£593,640
Total	£1,089,504	£1,439,055	£2,037,691	£2,885,355	£4,085,640
Type 1 GVA					
Total	£533,506	£704,674	£997,813	£1,412,895	£2,000,649
Type 2 GVA					
Induced total	£597,366	£789,022	£1,117,249	£1,582,016	£2,240,122
Induced effect	£63,860	£84,348	£119,436	£169,121	£239,473
Type 1 employment effect					
Effect	6,794,270	8,974,112	12,707,273	17,993,399	25,478,513
FTE	7	9	13	18	25
Type 2 employment effect					
Effect	7,694,497	10,163,164	14,390,961	20,377,489	28,854,365
FTE	8	10	14	20	29
Induced FTE	1	1	2	2	3

Table G4 Projected economic impact of seaweed production (cultivation) under the higher growth scenario

Higher growth	2021	2025	2030	2035	2040
Turnover	£0	£180,000	£1,080,000	£1,980,000	£2,880,000
Adjustment for T - S	£0	£5,400	£32,400	£59,400	£86,400
Direct	£0	£174,600	£1,047,600	£1,920,600	£2,793,600
Output effect					
Indirect effect	£0	£74,903	£449,420	£823,937	£1,198,454
Total	£0	£249,503	£1,497,020	£2,744,537	£3,992,054
Type 1 GVA					
Total	£0	£100,032	£600,195	£1,100,357	£1,600,519
Type 2 GVA					
Induced total	£0	£112,006	£672,037	£1,232,067	£1,792,098
Induced effect	£0	£11,974	£71,842	£131,710	£191,579
Type 1 employment effect					
Effect	0	1,273,926	7,643,554	14,013,182	20,382,810
FTE	0	1	8	14	20
Type 2 employment effect					
Effect	0	1,442,718	8,656,310	15,869,901	23,083,492
FTE	0	1	9	16	23
Induced FTE	0	0	1	2	3

Table G5 Projected economic impact of human food products under the BAU scenario

BAU	2021	2025	2030	2035	2040
Turnover	£1,984,500	£2,593,197	£3,520,727	£4,609,477	£5,999,028
Adjustment for T - S	£59,535	£77,796	£105,622	£138,284	£179,971
Direct	£1,924,965	£2,515,401	£3,415,105	£4,471,193	£5,819,057
Output effect					
Indirect effect	£548,615	£716,889	£973,305	£1,274,290	£1,658,431
Total	£2,473,580	£3,232,290	£4,388,410	£5,745,483	£7,477,488
Type 1 GVA					
Total	£1,025,805	£1,340,446	£1,819,894	£2,382,678	£3,100,948
Type 2 GVA					
Induced total	£1,212,017	£1,583,773	£2,150,254	£2,815,199	£3,663,856
Induced effect	£186,212	£243,328	£330,361	£432,521	£562,907
Type 1 employment effect					
Effect	18,933,409	24,740,770	33,590,004	43,977,381	57,234,592
FTE	19	25	34	44	57
Type 2 employment effect					
Effect	21,558,433	28,170,957	38,247,094	50,074,630	65,169,889
FTE	22	28	38	50	65
Induced FTE	3	3	5	6	8

Table G6 Projected economic impact of human food products under the higher growth scenario

Higher growth	2021	2025	2030	2035	2040
Turnover	£2,079,000	£3,368,734	£5,817,737	£9,583,202	£15,647,520
Adjustment for T - S	£62,370	£101,062	£174,532	£287,496	£469,426
Direct	£2,016,630	£3,267,672	£5,643,205	£9,295,706	£15,178,094
Output effect					
Indirect effect	£574,740	£931,287	£1,608,313	£2,649,276	£4,325,757
Total	£2,591,370	£4,198,958	£7,251,518	£11,944,982	£19,503,851
Type 1 GVA					
Total	£1,074,653	£1,741,327	£3,007,238	£4,953,638	£8,088,336
Type 2 GVA					
Induced total	£1,269,732	£2,057,426	£3,553,134	£5,852,860	£9,556,591
Induced effect	£195,079	£316,099	£545,896	£899,221	£1,468,255
Type 1 employment effect					
Effect	19,835,000	32,139,893	55,504,959	91,429,922	149,287,423
FTE	20	32	56	91	149
Type 2 employment effect					
Effect	22,585,025	36,595,932	63,200,451	104,106,234	169,985,396
FTE	23	37	63	104	170
Induced FTE	3	4	8	13	21

Table G7 Projected economic impact of bioactive products under the BAU scenario

BAU	2021	2025	2030	2035	2040
Turnover	£651,630	£871,554	£1,522,138	£2,504,215	£3,512,291
Adjustment for T - S	£19,549	£26,147	£45,664	£75,126	£105,369
Direct	£632,081	£845,407	£1,476,474	£2,429,089	£3,406,922
Output effect					
Indirect effect	£47,406	£63,406	£110,736	£182,182	£255,519
Total	£679,487	£908,813	£1,587,209	£2,611,270	£3,662,441
Type 1 GVA					
Total	£545,803	£730,010	£1,274,937	£2,097,521	£2,941,881
Type 2 GVA					
Induced total	£635,002	£849,314	£1,483,297	£2,440,315	£3,422,667
Induced effect	£89,200	£119,304	£208,361	£342,794	£480,786
Type 1 employment effect					
Effect	2,454,252	3,282,558	5,732,870	9,431,694	13,228,438
FTE	2	3	6	9	13
Type 2 employment effect					
Effect	3,711,696	4,964,387	8,670,126	14,264,054	20,006,074
FTE	4	5	9	14	20
Induced FTE	1	2	3	5	7

Table G8 Projected economic impact of bioactive products under the higher growth scenario

Higher growth	2021	2025	2030	2035	2040
Turnover	£700,350	£1,242,317	£2,931,093	£7,822,939	£16,067,077
Adjustment for T - S	£21,011	£37,270	£87,933	£234,688	£482,012
Direct	£679,340	£1,205,047	£2,843,160	£7,588,251	£15,585,065
Output effect					
Indirect effect	£50,950	£90,379	£213,237	£569,119	£1,168,880
Total	£730,290	£1,295,426	£3,056,397	£8,157,370	£16,753,945
Type 1 GVA					
Total	£586,610	£1,040,560	£2,455,072	£6,552,464	£13,457,722
Type 2 GVA					
Induced total	£682,479	£1,210,617	£2,856,300	£7,623,320	£15,657,092
Induced effect	£95,869	£170,057	£401,228	£1,070,857	£2,199,370
Type 1 employment effect					
Effect	2,637,747	4,678,973	11,039,456	29,463,749	60,513,872
FTE	3	5	11	29	61
Type 2 employment effect					
Effect	3,989,206	7,076,260	16,695,559	44,559,603	91,518,364
FTE	4	7	17	45	92
Induced FTE	1	2	6	15	31

Table G9 Projected economic impact of all other products under the BAU scenario

BAU	2021	2025	2030	2035	2040
Turnover	£2,450,000	£6,350,000	£6,350,000	£6,350,000	£6,350,000
Adjustment for T - S	£73,500	£190,500	£190,500	£190,500	£190,500
Direct	£2,376,500	£6,159,500	£6,159,500	£6,159,500	£6,159,500
Output effect					
Indirect effect	£539,466	£1,398,207	£1,398,207	£1,398,207	£1,398,207
Total	£2,915,966	£7,557,707	£7,557,707	£7,557,707	£7,557,707
Type 1 GVA					
Total	£1,455,242	£3,771,749	£3,771,749	£3,771,749	£3,771,749
Type 2 GVA					
Induced total	£1,723,460	£4,466,927	£4,466,927	£4,466,927	£4,466,927
Induced effect	£268,218	£695,178	£695,178	£695,178	£695,178
Type 1 employment effect					
Effect	15,109,501	39,161,359	39,161,359	39,161,359	39,161,359
FTE	15	39	39	39	39
Type 2 employment effect					
Effect	18,890,569	48,961,270	48,961,270	48,961,270	48,961,270
FTE	19	49	49	49	49
Induced FTE	4	10	10	10	10

Table G10 Projected economic impact of all other products under the higher growth scenario

Higher growth	2021	2025	2030	2035	2040
Turnover	£2,450,000	£7,425,000	£11,341,750	£15,393,046	£22,555,575
Adjustment for T - S	£73,500	£222,750	£340,253	£461,791	£676,667
Direct	£2,376,500	£7,202,250	£11,001,498	£14,931,255	£21,878,908
Output effect					
Indirect effect	£539,466	£1,634,911	£2,497,340	£3,389,395	£4,966,512
Total	£2,915,966	£8,837,161	£13,498,837	£18,320,649	£26,845,420
Type 1 GVA					
Total	£1,455,242	£4,410,274	£6,736,730	£9,143,104	£13,397,476
Type 2 GVA					
Induced total	£1,723,460	£5,223,139	£7,978,389	£10,828,285	£15,866,788
Induced effect	£268,218	£812,865	£1,241,658	£1,685,181	£2,469,312
Type 1 employment effect					
Effect	15,109,501	45,791,038	69,946,197	94,931,119	139,103,462
FTE	15	46	70	95	139
Type 2 employment effect					
Effect	18,890,569	57,249,989	87,449,839	118,687,099	173,913,321
FTE	19	57	87	119	174
Induced FTE	4	11	18	24	35

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