Seaweed: Kelp is on the way

Abstract

- Seaweed will be one of the next big themes for sustainability investors, in our view. This report provides a deep dive into seaweed-related opportunities and challenges.
- Seaweed products – whose uses range from food, food ingredients, animal feed, fertiliser and plastic alternatives to biofuels – can help to mitigate greenhouse gas emissions and address malnutrition. We believe this could drive a seven-fold increase in production between now and 2040.
- The outlook for seaweed investing appears compelling. We estimate USD100bn of investment requirements until 2040, generating USD313bn of value and c.200mn new jobs.
- Key challenges remain, including the need to establish large-scale ocean-focused investment funds that make it easier for seaweed operators to access funding.

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Contents

Sustainability and Environmental, Social and Governance (ESG) criteria help investors evaluate adherence to these standards. Standard Chartered Research believes in providing insights and analysis on sustainability and ESG factors with a view to supporting clients and communities in the transition towards a cleaner, greener and fairer world.

Executive summary

This report provides a deep dive into the role that seaweed can play in achieving long-term sustainability targets, and the associated investment opportunities. With the world's population projected to increase to c.10bn by 2050, sustainability challenges – especially those associated with the natural world – will become increasingly difficult to solve unless stronger action is taken. We argue that seaweed can play an important role in reducing greenhouse gas (GHG) emissions, which will result in both opportunities and disruption for businesses and investors exposed to a range of end markets, including agriculture, food, chemicals, pharmaceuticals, packaging and plastics.

The 'blue economy' and seaweed matter for the SDGs
Improving the sustainability of the ocean (or the 'blue economy') is of prime importance, as it generates 50% of the world's oxygen, and absorbs over 25% of human-caused carbon dioxide and around 90% of excess heat. Expanding the seaweed industry should be a key goal, as it would have a direct positive impact on most of the UN Sustainable Development Goals (SDGs), in our view.

Strong growth outlook
Although global seaweed production has increased around eight-fold since the early 1980s, it remains highly concentrated; China and Indonesia account for 90% of production. Our assessment of the growth potential of just a sample of seaweed end markets indicates that these alone could drive a seven-fold increase in global seaweed production between now and 2040. With the right regulatory and policy approach, seaweed can help mitigate GHG emissions and address malnutrition.

Investment and economic opportunities
Our analysis of seaweed as a food alternative, biostimulant, animal feed ingredient, plastic alternative and methane reducer suggests that achieving long-term growth potential may require total investments of c.USD100bn between now and 2040. This may seem aggressive, but our modelling for seaweed farming suggests that these investments could generate c.USD313bn of value and generate 200mn jobs. Our financial analysis suggests that a seaweed farm can generate an internal rate of return of over 20%.

Key challenges remain
Capturing seaweed's growth potential is not without its challenges. These include uncertainty around carbon sequestration, the lack of a well-defined carbon credit market, and the fact that seaweed farming may raise its own environmental concerns.

One of the biggest obstacles is a lack of funding for seaweed companies. We see a need for increased global collaboration to establish investment support programmes for the seaweed industry so that smallholder farmers can get better access to funding. These programmes should also be designed to facilitate the establishment of larger commercial enterprises that can operate in a more automated way and scale up seaweed production more rapidly. We believe that a guaranteed, pooled investment approach would work well to attract sufficient capital to unlock the industry's potential and help to achieve sustainability targets.

Given the role that seaweed can play in supporting the SDGs, we expect interest in the topic to accelerate over the next few years. This is likely to create an increasing range of investment opportunities for investors, most of which we expect to be debt-focused. Ahead of this, we hope that this report will help fixed income investors to build their seaweed knowledge base.

Seaweed and the SDGs

Seaweed has the potential to support a wide range of sustainable end markets, some of which we will review in this report. The contribution of seaweed to achieving long-term sustainability targets should not be underestimated. In fact, our analysis suggests that a strong expansion of seaweed production and consumption would support the majority of the 17 UN SDGs, as we summarise in Figure 1.

Figure 1: A sound seaweed supply chain supports most of the SDGs, in our view

SDGs supported by seaweed

SDG 1. Seaweed supports economic development
SDG 2. Greater seaweed production increases food security, especially in developing countries
SDG 3. Seaweed provides high-quality nutrients, which support healthier diets
SDG 5. Expanding seaweed farming in developing countries enables greater inclusivity across the entire supply chain
SDG 6. Pressure on freshwater usage is reduced if consumers switch to seaweed, as it requires no fresh water
SDG 7. Green energy potential if seaweed is used as a biofuel
SDG 8. Expanding seaweed production aids economic development, especially in coastal communities
SDG 10. A thriving seaweed economy strengthens the livelihood of fishing families and communities
SDG 11. Integrating seaweed into fishing areas allows underdeveloped fishing communities in EM to improve
SDG 12. Seaweed can function as a highly efficient resource use, and form part of circular economy solutions
SDG 13. Seaweed could be used for carbon sequestration; GHG emissions can be averted by seaweed usage
SDG 14. Ocean regeneration: assimilation of nitrogen, phosphorus and CO2, enhancement of biodiversity
SDG 15. Seaweed can displace land and water-intense traditional agriculture and reduce fertiliser needs

Source: United Nations, Standard Chartered Research
https://www.un.org/sustainabledevelopment/
Note: The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States

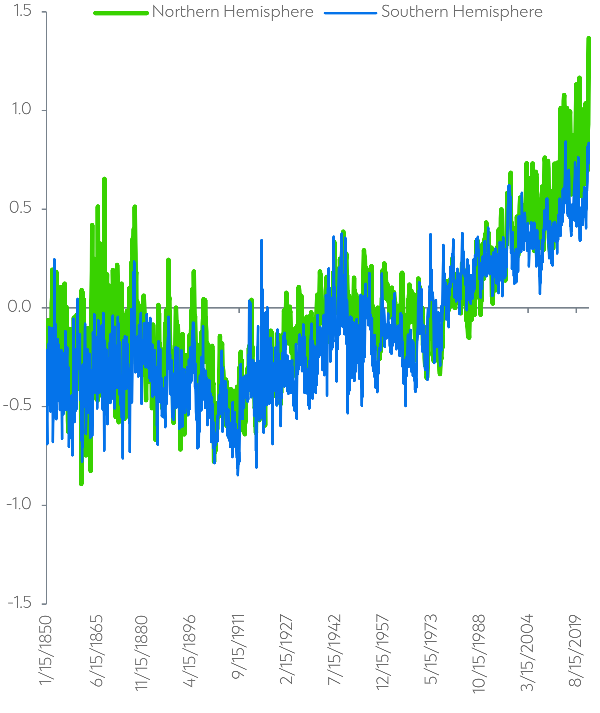
SDG 14 ('Life below water') a key beneficiary of the seaweed revolution

While seaweed has the potential to support several of the SDGs, the most directly relevant one is SDG 14: *Conserve and sustainably use the oceans, seas, and marine resources for sustainable development* (briefly described as 'Life below water').

The oceans (or the 'blue economy') form a vital part of the world's ecosystem. The UN highlights that ocean-linked sectors contribute USD1.5tn to the global economy and support around 31mn jobs; it considers two-thirds of the global economy to be moderately or highly dependent on ocean resources. The social benefits of a vital and sustainable blue economy are also high, as the livelihoods of more than 3bn people across the world are supported by the oceans.

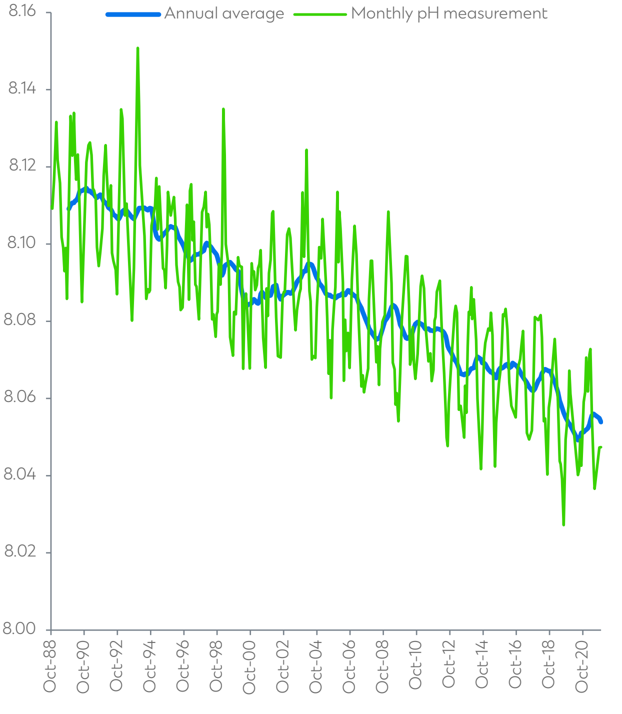
Global warming poses a clear threat to oceans as average water temperatures have risen since the late 1960s. Water temperature readings for oceans in the Northern and Southern Hemisphere are currently well over 1°C above the 1951-80 mean (Figure 2). This is putting increasing pressure on ocean ecosystems and also leads to rising sea levels and increased water vapour levels over the oceans – both of which increase the risk of flooding and heavy rain, and even contribute to lengthening the growth season for some bacteria that contaminate seafood. The gradual increase in the acidification of the oceans has negatively impacted the biodiversity and health of ocean ecosystems (Figure 3).

Figure 2: Sea surface water temperature anomaly
°C



Source: NASA, GISS, Standard Chartered Research

Figure 3: Seawater pH, Hawaii
pH



Source: University of Hawaii, Standard Chartered Research

The UN has established 10 targets in relation to SDG 14. Nine of these, in our view, are directly relevant to seaweed or are more likely to be met through a further expansion of sustainable seaweed production (Figure 4). The UN's latest assessment of progress towards SDG targets indicated that only one country (Jordan) is on track to achieving the targets associated with SDG 14. For more than 100 countries, the trend shows no improvement; 16 countries show a deterioration.

Figure 4: SDG 14 and the relevance for seaweed

	Target	Seaweed relevance
14.1	**Reduce marine pollution**	Sustainable seaweed farming makes no use of plastic elements in the production process. Furthermore, the development of bioplastics helps to reduce plastic consumption and thereby plastic debris density in the oceans
14.2	**Protect and restore ecosystems**	Seaweed production can help improve the biodiversity structure and overall health of marine ecosystems
14.3	**Reduce ocean acidification**	Seaweed production directly reduces ocean acidification through absorption of carbon dioxide and nitrogen
14.4	**Sustainable fishing**	Seaweed production, when integrated into fish-farm operations, improves the overall sustainability of the operation
14.5	**Conserve coastal and marine areas**	Developing and protecting seaweed forests can help protect overall coastal structures through wave-breaking and improved water quality, among others
14.6	**End subsidies contributing to overfishing and illegal fishing**	Strong support for integrating seaweed farming into fish farms improves productivity and profitability, reducing the need for subsidies
14.7	**Increase the economic benefits from sustainable use of marine resources**	Expanding seaweed farming capacity improves economic conditions for coastal communities
14.8	**Increase scientific knowledge, research and technology for ocean health**	Collaboration between stakeholders is increasing (e.g., Oceans 2050); this aids development of knowhow and technological innovation
14.9	**Support smallholder farmers**	Seaweed farming in Asia is mostly by smallholder farmers. Financial support to expand production capacity and invest in technology would aid local economies and sustainability targets
14.10	**Implement and enforce international sea law**	

Source: United Nations, Standard Chartered Research

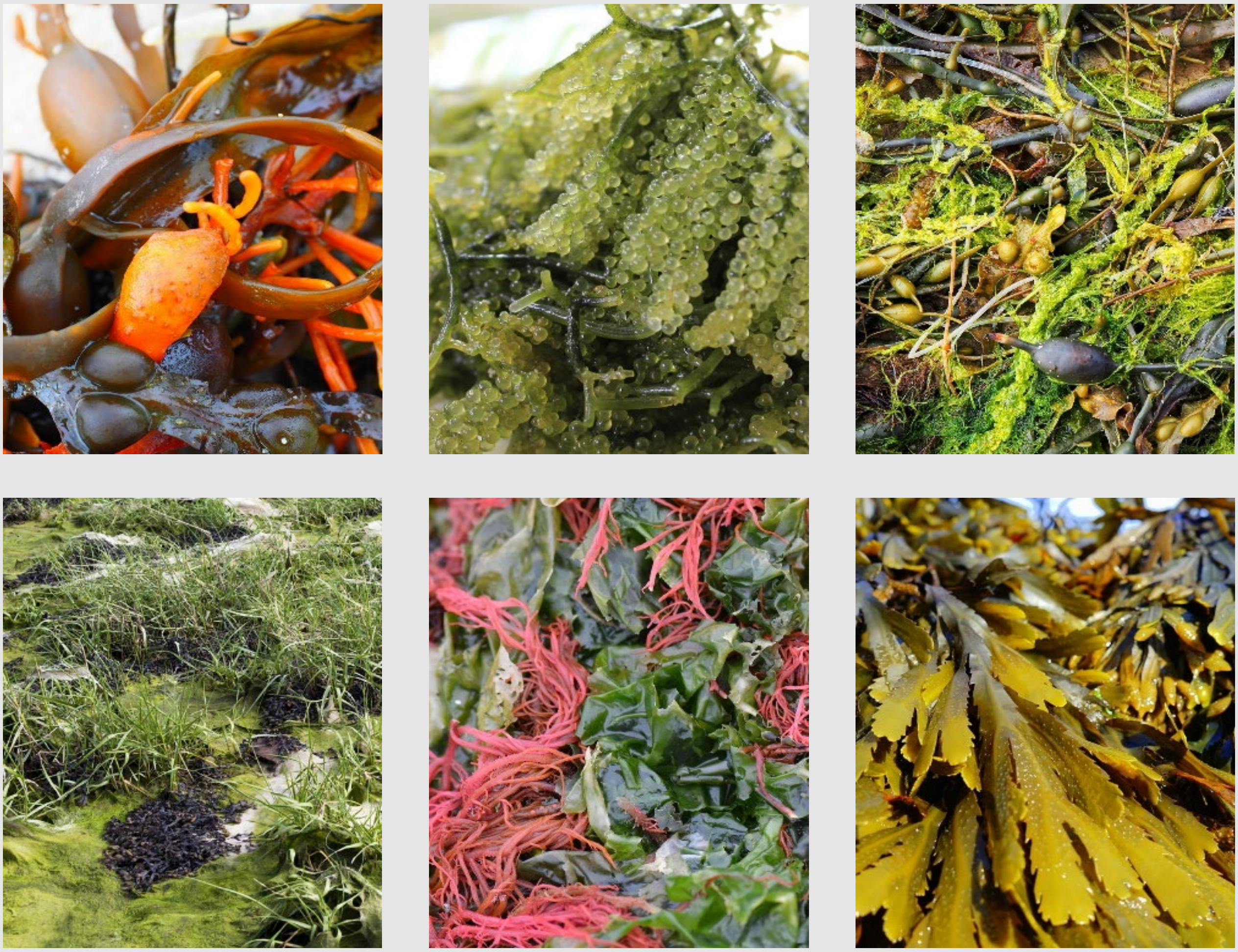
Seaweed: A rapidly expanding growth market

Seaweed has been cultivated for centuries, but the pace of production growth only started to accelerate rapidly during the past 20 years (Figure 6). We believe this has been driven by an improving understanding of the sustainability characteristics of seaweed and its wide range of potential end markets. Seaweed's current uses include animal feed, consumer goods (primarily food) and biostimulants used in agriculture. Emerging and future end markets include bioplastics, biofuels, pharmaceuticals, textiles and construction materials.

Seaweed is a macroalgae and includes more than 12,000 species of multicellular marine algae. These species are grouped into red seaweed (e.g., carrageenan), brown seaweed (e.g., kelps) and green seaweed (e.g., sea lettuce). Common features of seaweed include the existence of an algal body, a leaf-like structure, a stem, and a basal structure that allows the weed to attach to a substrate.

Growing requirements for seaweed include seawater and light so that photosynthesis can occur. Most seaweed species also need to have an attachment point. Depending on the species, seaweed can grow in nearshore waters, on rocky shores, or in deeper waters in the case of some red seaweed species.

Figure 5: Seaweed examples



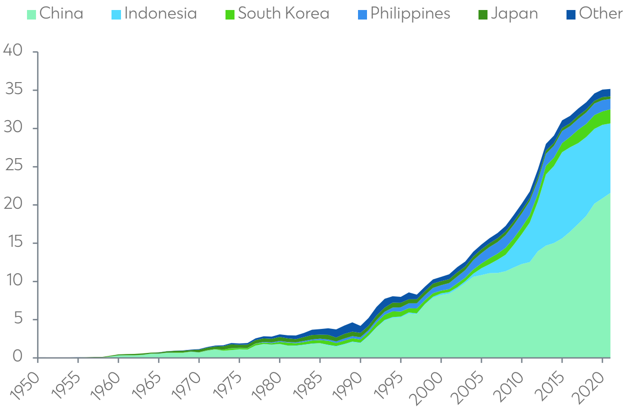
Seaweed production started to accelerate in the 1990s

The use of seaweed for human consumption dates back to the 15th century, when laver (an edible seaweed) was first cultivated in Korea; seaweed farming in Japan began as early as 1670. Larger-scale commercial seaweed farming started around 50 years ago, but data from the UN Food and Agriculture Organization (FAO) indicates that production volumes have only started to grow more aggressively during the past 20 years (Figure 6).

Seaweed production is currently dominated by Asian producers, which make up more than 98% of the global market. China and Indonesia had respective 61% and 26% shares of global wet seaweed volumes in 2021, based on FAO data (Figure 7). Japan's share of production has fallen steadily over the years, from c.17% in 1980 to just 1% in 2021. Indonesia appears to have been the main beneficiary, given that its share was just 1% in 1980.

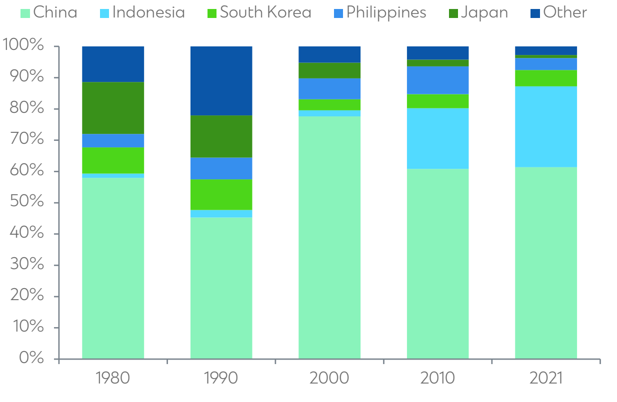
FAO data indicates that after a period of accelerating growth from 2005-15, seaweed volume expansion has slowed during the past seven years. Analysis from Hatch Innovation Services suggests a variety of reasons for this, including the negative impact of climate change on commercial seaweed yields, a lack of quality seed supply, and increasing labour challenges in Asia.

Figure 6: Seaweed production since 1950
Million tonnes of wet-weight



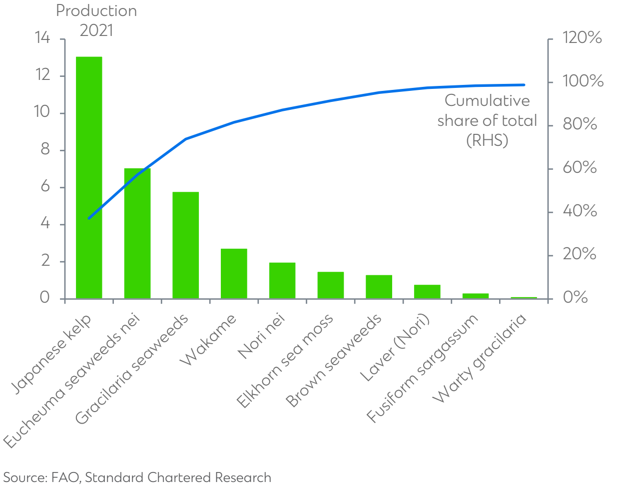
Source: FAO, Standard Chartered Research

Figure 7: Share of seaweed market by country
% of annual global seaweed production



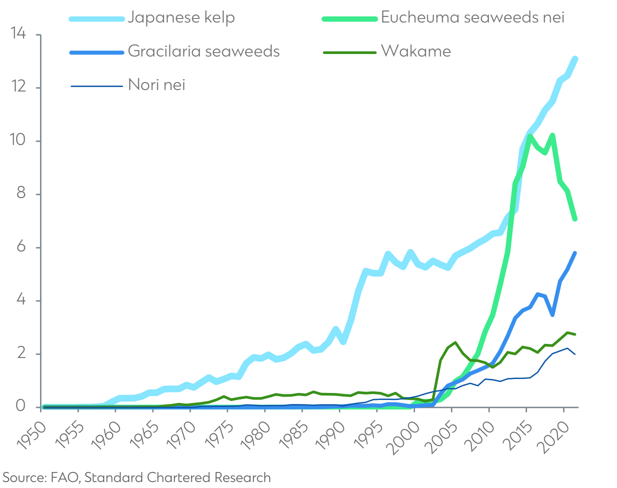
Source: FAO, Standard Chartered Research

Figure 8: Seaweed species with highest production
Million tonnes of wet-weight production, 2021



Source: FAO, Standard Chartered Research

Figure 9: Annual production of key seaweed species
Million tonnes of wet-weight production



Source: FAO, Standard Chartered Research

Despite the wide variety of seaweed species, only a very small percentage are commercially farmed today. Just 10 species account for 99% of global seaweed production, according the FAO's FishStat database, which records production volumes for 45 different seaweed species; three species represent 74% of global production (Figure 8).

Figure 9 shows how production volumes for key seaweed species have changed over time. Japanese kelp has shown strong growth since the 1950s, as it is widely used in soups and salads and now represents 37% of the total market. Gracilaria seaweeds have also seen strong production growth, especially since 2000; some 5.8 million tonnes (Mt) have been produced since 2021, up from just 55,000 tonnes in 2000. This red seaweed is mainly used as a thickener in foods. Eucheuma seaweeds have seen a sharp production decline in the past five years, mainly due to falling production in Indonesia, where volumes declined from a high of 10.2Mt in 2018 to 7Mt in 2021. This has had a significant impact on Indonesia's overall seaweed market, given that eucheuma accounted for c.99% of the country's seaweed production in 2018. Factors driving the decline in eucheuma production include the impact of warming seawaters on growth and harvesting policies, as well as COVID-related production challenges.

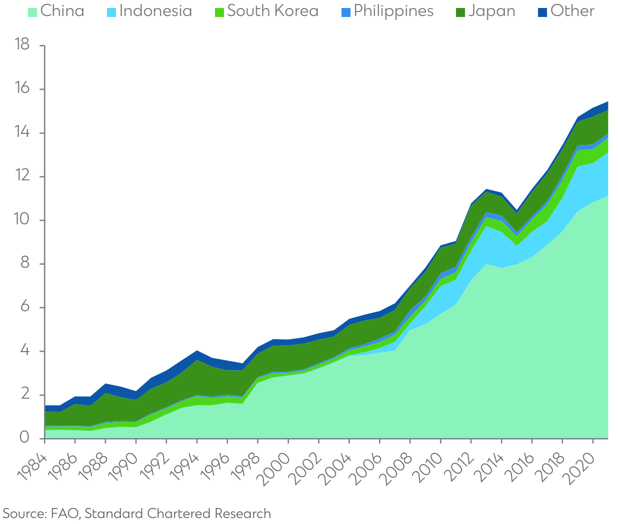
The total value of seaweed has risen 10-fold since 1984

The value of the global seaweed market has increased more than 10-fold since 1984, growing at an annual average rate of 6.5% to reach USD15.5bn by end-2021, according to FAO data (Figure 10).

The FAO provides seaweed production data in both value and volume terms, making it possible to track the development of the market globally, by country and by species over time. China has moved up the seaweed value chain in recent decades – its seaweed was valued at USD0.50 per kilogramme at end-2021, more than doubling from USD0.21 in 1984. It accounted for 61% of the global seaweed market by volume and 72% by value in 2021. In contrast, the value of seaweed produced in the Philippines and South Korea was lower in 2021 than in the 1980s (Figure 11).

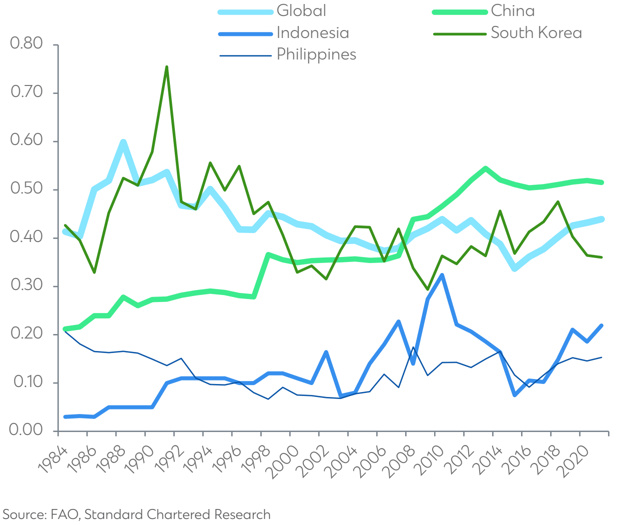
To better understand the economics of the global seaweed market, we have also looked at the evolution of seaweed value by species over time. With the exception of Japanese kelp, all of the main seaweed products have experienced significant volatility in value per kilogramme of final product (Figure 12). Comparing the change in value for a specific type of seaweed with the change in production gives us a more detailed picture

Figure 10: Value of global seaweed market
USDbn



Source: FAO, Standard Chartered Research

Figure 11: Value of seaweed market by country
USD per kg of seaweed



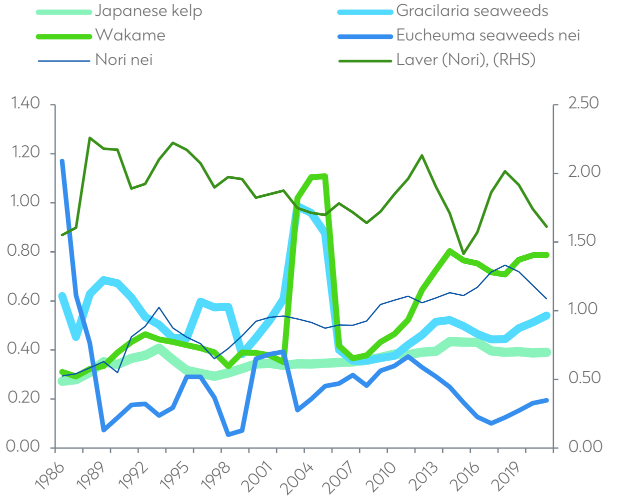
Source: FAO, Standard Chartered Research

of value creation across seaweed species. Few species have seen consistent increases in value per kilogramme, according to FAO data. This apparent lack of pricing power is a potential concern, as it may indicate that strong supply-led expansion of seaweed production would result in price declines, pressuring the profitability of seaweed farming.

Pricing power is key to attracting investment in seaweed production capacity. Close to 90% of current seaweed production is used as food ingredients; given this, we assess seaweed pricing power by comparing seaweed value per kilogramme with broader food prices (using the FAO's nominal food price index) over time. We find that seaweed value creation has significantly lagged that of food commodity prices more broadly, especially since 2004 (Figure 14).

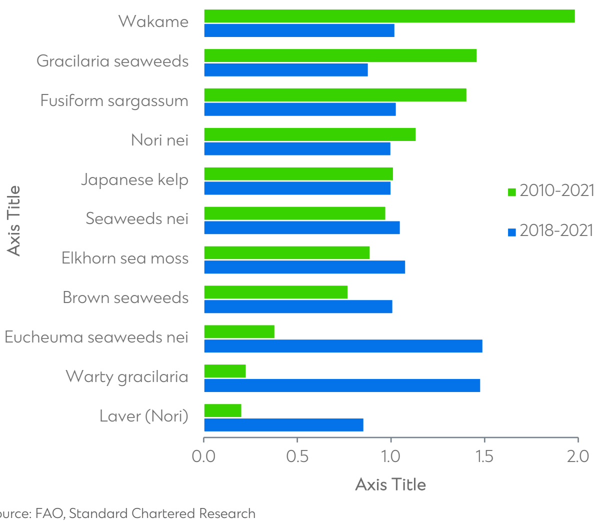
Our analysis of seaweed's relative value suggests that the profitability of seaweed farming can only be sustained or improved if demand growth from current seaweed end markets accelerates, or if new end markets are established. We explore some of these markets in the **Seaweed as a sustainable disruptor** section.

Figure 12: Value per kilogramme of seaweed
Rolling three-year average (UDS/kg)



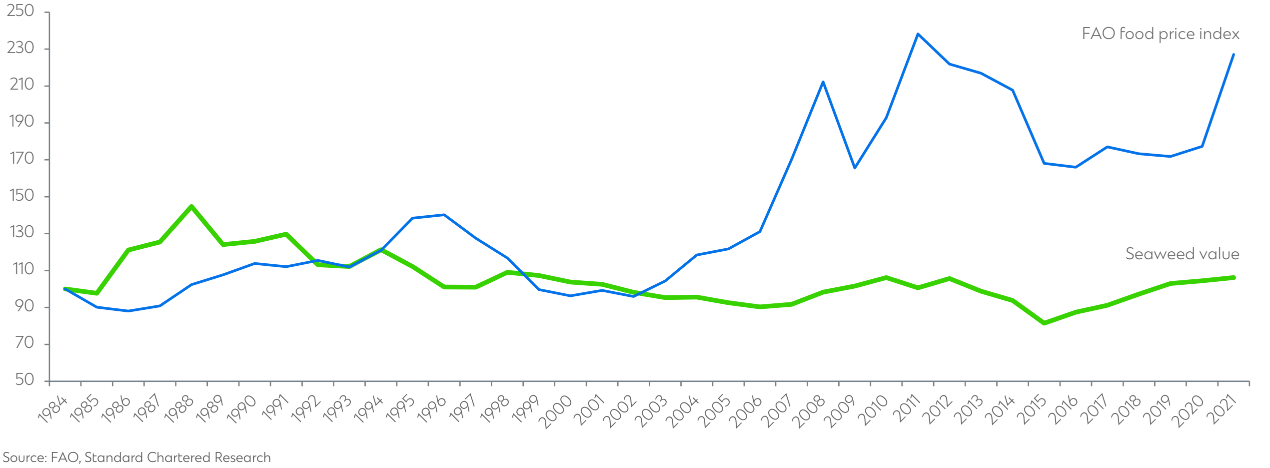
Source: FAO, Standard Chartered Research

Figure 13: Comparing value versus production changes
Change in value versus change in production



Source: FAO, Standard Chartered Research

Figure 14: FAO food price index versus seaweed value development
Rebased to 1984



Source: FAO, Standard Chartered Research

The seaweed production process

The production and environmental footprint of seaweed differs substantially from more traditional food production methods in that it does not require land, fresh water or the use of fertilisers. A wide variety of seaweed production strategies have been developed over the years depending on the type of seaweed produced, the climate or location of the production site, and the ability of the seaweed farmer to invest in more efficient and specialised machinery and equipment.

Where is seaweed produced?

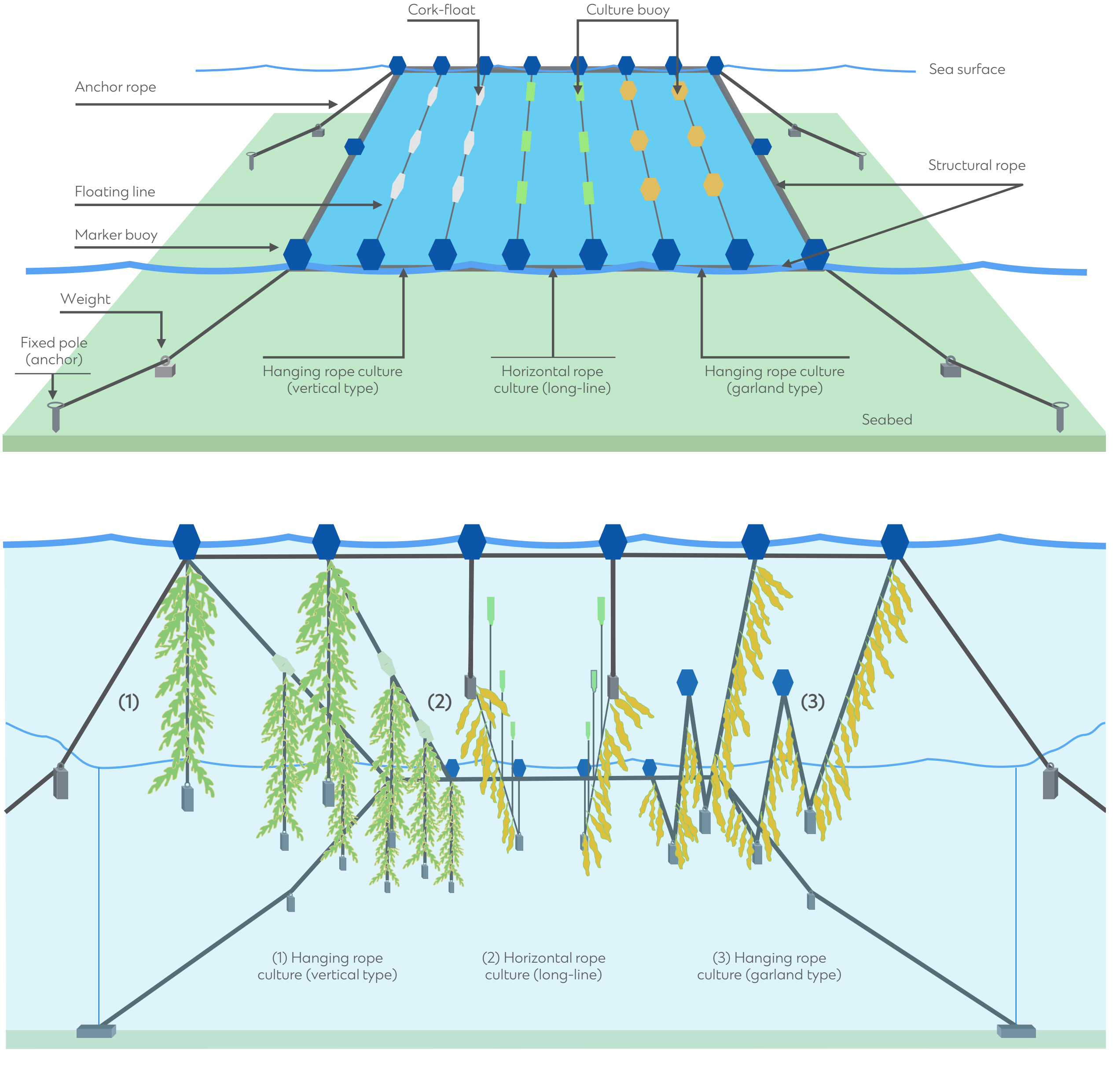
Seaweed farming originally occurred relatively close to shorelines, but the range of potential seaweed farming locations has increased more recently. Broadly speaking, there are six different types of locations.

- **Onshore:** Seedlings are deployed in onshore water ponds, greenhouses and raceway systems for cultivation in highly controlled environments in terms of light, temperature and nutrient content. The mature seaweed is collected from the tanks manually or via automated systems. While seaweed farming has strong sustainability potential, onshore production may limit some of these benefits owing to the need for land, and the electricity use required to create the controlled environments.
- **Offshore:** Seaweed seedlings are deployed at sea, attached to cultivation substrates such as ropes. These ropes are suspended several metres below the surface, and separated from each other so that boats can be used to harvest the mature seaweed.
- **Wild harvesting:** As seaweed occurs naturally in the ocean, it can be harvested directly in the wild. This approach is not suitable for large-scale, optimised farming practices.
- **Co-location (e.g., windfarms):** Seaweed farms may be created by attaching substrates to offshore windfarms. This approach has the potential to create equipment and labour synergies and should therefore lead to improved environmental performance.
- **Nearshore:** In contrast to offshore production, seaweed can also be farmed closer to shore in shallower water. The approach is similar, although seedlings can be deployed with sheets or nets as well as ropes.
- **Integrated multi-trophic aquaculture:** Seaweed production can be integrated into broader marine culture systems, including fish (e.g., salmon) or bivalves (e.g., oysters or mussels). Benefits of this approach include reduced environmental impact as seaweed can be used as fish food and can also clean up excess nutrients or waste; it can also improve productivity and expand farmers' range of revenue streams.

The structure of a seaweed farm

While different seaweed farm designs have been developed based on the type of seaweed species being produced, there are commonalities between them. For example, anchors, culture lines and ropes are equipment used by all seaweed farms. Key differences include the type of cultivation method used, the distance between the cultivation lines, the size of the farm, the type of anchor and floater, and whether boats are used (and if so, how many). Various cultivation methods are used; they differ primarily in whether single lines or so-called 'rafts' are used, and whether or how these lines or rafts are attached to the seafloor. The pictures below show some of the most widely used cultivation methods today.

Figure 15: Typical seaweed cultivation using seeded ropes



Source: Tullberg et al (2022), Standard Chartered Research

The success of seaweed farming depends on a wide range of factors that differ between seaweed species. Figure 16 summarises some of these factors for key seaweed species (based on surveys conducted by Hatch Innovation Services, an aquaculture consultancy). A few conclusions can be drawn from the survey data.

- The data suggests that farms in China, especially those that produce Japanese kelp and wakame, are substantially larger than any of the farms reviewed in other countries. For example, some Japanese kelp farms in China have sizes of up to 2,000 ha, compared to 15-20ha for farms in South Korea. The cultivation lines used on farms in China also tend to be longer, indicating an ability to produce substantially more seaweed. The larger wakame seaweed farms in China had total line length of up to 800km – around 8x the maximum observed in South Korea and 40x that in Japan.
- China's seaweed farms, especially wakame farms, are located much further offshore than farms in other countries.

Size and location differences between farms in China and elsewhere indicate that China's seaweed farming sector is more geared towards mass-market production. The potential impact of this may be that seaweed can be produced more cheaply in China than in other countries. This could negatively impact the market position of seaweed farmers in other countries trying to compete with Chinese producers.

Figure 16: Key seaweed farm characteristics

	Japanese kelp	Eucheuma seaweed nei	Wakame	Nori nei	Gracilaria
Typical farm area (hectare)					
Indonesia		0.25-1.0			1-3
Philippines		0.125-1.0			
Malaysia		0.25-0.50			
South Korea	15-20		10-20	10-100 (max 450)	
Japan			1-4		
China	15-2,000		150-300	600-2,500 (max 7,000)	
Typical farm size (length of lines, metres)					
Indonesia		1,000-30,000			
Philippines		1,000-10,000			
Malaysia		1,000-10,000			
South Korea	6,000-100,000		6,000-100,000		
Japan	2,000-20,000		2,000-20,000		
China	Greater than 100,000		400,000-800,000		
Distance from shore (km)					
Indonesia		0.1-5.0			Land-based
Philippines		0.1-3.0			
Malaysia		0.05-2.0			
South Korea	2		1-2	2-10	
Japan	0.3		1-3		
China	0.5-1.0		10-15	0.7-30	Often in bays, estuaries
Cultivation method					
Indonesia		Hanging long line, fixed off-bottom, floating raft			Pond scattering
Philippines		Hanging long line, fixed off-bottom			
Malaysia		Hanging long line			
South Korea	Hanging long line, fixed off-bottom, floating raft		Horizontal raft type, single horizontal long line	Floating turnover net, floating net, fixed net	
Japan	Hanging long line, fixed off-bottom		Single or double horizontal long line	Fixed net, floating net	
China	Hanging long line		Horizontal raft type	Fixed net, floating net, semi-floating net	Pond scattering

Source: Hatch Innovation Services, Standard Chartered Research

Productivity differs substantially between seaweed farms

In addition to the structure of the farm, the type of seaweed produced determines the profitability of seaweed farming. Seaweed farms in China are by far the most efficient at producing Japanese kelp, the seaweed species with the largest market share. Farms in China surveyed by Hatch generated a yield of 3.75kg of kelp per metre of line, or 50% more than farms in South Korea and Japan.

Further innovation set to increase profitability

As Figures 16-17 show, yields vary widely across seaweed farms. The much higher yields and larger areas of some farms (particularly those in China) have clearly helped to drive the size of the overall seaweed market in the past 10-20 years. However, we believe that seaweed farming capabilities need to increase further if the sector's long-term potential is to be achieved.

If seaweed farming is to be deployed beyond its current markets (including in more developed regions), then farming systems need to be developed that allow much greater economies of scale; labour costs may otherwise make seaweed farming uneconomic in more developed markets. A 2022 report by Tullberg et al noted that seaweed farming cultivation systems need to overcome a range of challenges, including:

- Structures that are located further offshore need to be able to cope with infrequent but intense weather events. While occasional loss of seaweed crop may be acceptable, the long-term integrity of the system needs to be ensured in order for investment costs not to become excessive.

Figure 17: Production and yield characteristics for key seaweed species and by location
Units highlighted per section

	Japanese kelp	Eucheuma seaweed nei	Wakame	Nori nei	Gracilaria
Grow out time (days until first harvest)					
Indonesia		30-45			40-60
Philippines		30-60			
Malaysia		30-45			
South Korea	Early: 50-80, late: 90-120		Early: 50-80, late: 90-120	45-70, then partial every 10-15	
Japan	Early: 90, late: 120		Early: 90, late: 120	30, then partial every 20	
China	c150		c120	40-50, then partial every 10-15	60-90
Best growing season					
Indonesia		All year; region-dependent			Apr-Oct
Philippines		Region-dependent			
Malaysia		All year; winter is best			
South Korea	Dec-Jun		Oct-Apr	Jan-Feb (temp 5-8°C)	
Japan	Nov-Mar		Nov-Mar/Apr	Jan-Feb (temp 5-8°C)	
China	Oct-Feb		Oct-Apr	Dec-Feb	Jan-Apr
Number of harvests per year					
Indonesia		Varies by region			4-6
Philippines		3-4 to 8-10			
Malaysia		up to 10 times			
South Korea	1		1	Up to 10 times	
Japan	1		1	Up to 12 times	
China	1 (sometimes 2)		1	Up to 7-8 times	3-4
Average yield per year (wet weight)					
Indonesia		3-5kg/m			20-30Mt/ha
Philippines		2-5kg/m			
Malaysia		2-4kg/m			
South Korea	2-2.5kg/m		10-15kg/m	6-7Mt/ha	
Japan	1.7-2.3kg/m		10-15kg/m	N/A	
China	2.7-3.75kg/m		10-15kg/m	5.6Mt/ha	55-75Mt/ha

Source: Hatch Innovation Services, Standard Chartered Research

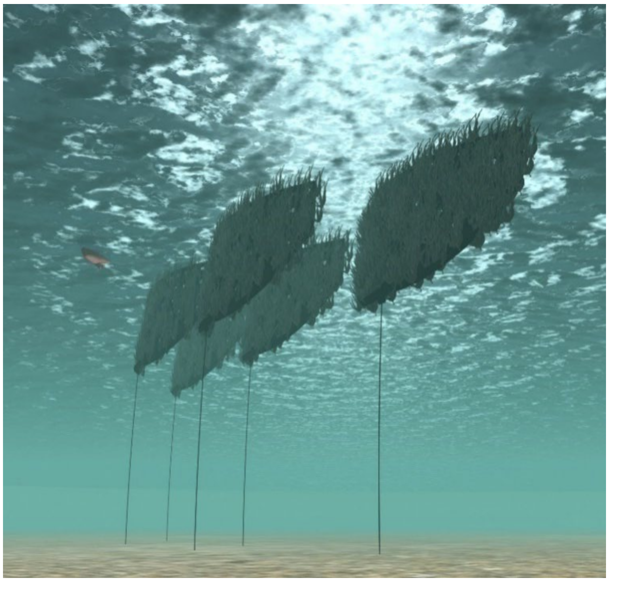
- Offshore waters near surface level typically have a lower nutrient density, which can impact seaweed growth rates unless strategies are developed to cope with this.
- Offshore harvesting and reseeding costs are likely higher than for nearshore systems. The need to reduce costs for offshore systems is therefore high.

Several new technologies and approaches to seaweed farming that are currently being developed and tested may substantially expand production volumes. Some of these take new approaches to the layout of the longlines, aiming to optimise production yields (for example, the Buland 10 system developed by Seaweed for Norway uses a triangulated longline layout). Other companies use vertical rather than horizontal sheet-like nets. Seaweed Energy Solutions, for example, makes vertical sheets that are moored to one point only, allowing the sheets to float freely (Figure 18).

3D circular-shaped systems are another recent development (Figure 19). Seatech Energy has developed a circular system with diameters of up to 200m, while Solvang et al (2021) developed a concept for automated kelp production that also uses submerged circular modules. Their calculations suggest that yields from their Standardized Production of Kelp (SPOKe) concept could be well above those achieved by more recently developed 2D and 3D systems.

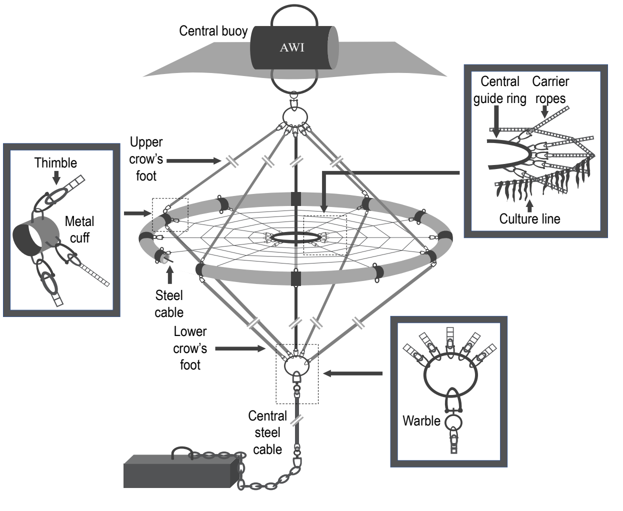
We expect innovation of seaweed production infrastructure to continue, and we believe that technology will play a greater role going forward. The potential for automation is key, as it would support much larger seaweed farms – which are needed if seaweed is to achieve its full potential in supporting climate change mitigation and adaptation.

Figure 18: Seaweed Energy Solutions' vertical sheet



Source: Seaweed Solutions AS, Standard Chartered Research

Figure 19: Circular sub-surface ring structure



Source: Tullberg et al (2022), Standard Chartered Research

Company profile:

Seatech Energy

Overview

Seatech Energy is a private company headquartered in the Netherlands. It was founded in 2015 with support from Inrada group, a company specialised in the design and manufacture of systems and controls for the offshore oil and gas industry.

Relevance to the seaweed industry

Seatech Energy launched its company with a multi-feed bio-digester. A key benefit of this product is that it disposes of waste and converts it into a biogas, which can be used as bioenergy. The company's digestion technology also produces a high-grade fertiliser that can be used for desert greening, among other things.

To minimise the impact of its bio-digester on land and water use, Seatech Energy explored the possibility of using seaweed as feedstock. Recognising that this required increased seaweed production, and using its offshore oil and gas-related knowledge, the company developed offshore marine structures that allows seaweed cultivation on an industrial scale.

Seatech Energy has developed so-called pods or circular frameworks with a diameter ranging from 20-200 metres. The system can support different growth materials, can be applied at variable depths to accommodate different weather and wave conditions, and has a modular design that allows it to be adjusted to any local farm conditions.

Seatech Energy estimates that its pods can deliver yields of between 800-1000 tonnes per hectare per year; according to the company, this is up to 40 times the yield of traditional farms. As a result, the company claims that seaweed production costs for its pods are below USD40 per tonne, compared with a cost of c.USD100 per tonne for conventional farms.

Seatech Energy's view on the seaweed market

Seatech Energy believes that attracting sufficient investment funds is the key challenge for the seaweed industry. Assuming that this can be done, the company believes that the seaweed industry should be able to grow at an annual rate of more than 10% per year. End markets with especially strong growth prospects include biostimulants, animal feed, health supplements, human food and bioplastics.

Seaweed as a sustainable disruptor

While seaweed production has experienced strong growth over the past few decades, we see potential for significant further gains from here.

Figure 20: General composition of red, green and brown seaweed

Component	Share	Examples
Ash	10-50%	Macronutrients: sodium, calcium, magnesium Micronutrients: iodine, iron, zinc
Carbohydrates	35-74%	Polysaccharides: carrageenan, alginate, agar, fucoidan
Lipid	0.2-3.8%	Sterols, PUFAs
Pigments		Chlorophylls, carotenoids, phycobiliproteins
Polyphenols		Flavonoids, bromophenols, terpenoids, phlorotannins
Proteins	5-35%	Amino acids, peptides, lectins
Vitamins		Provitamins A, vitamins B, vitamins C, vitamins D
Water	80-90% (10-20% after drying)	

Source: World Bank, Ito and Hori (1989), Kim (2011), Peng et al (2015), Standard Chartered Research

The compounds found in seaweed, and their characteristics, have allowed an ever-widening range of potential end markets to be identified (see Figures 20 and 21). The sustainable characteristics of seaweed-based products, especially relative to products they can displace or disrupt, supports our positive view on future seaweed demand growth. In the following sections, we highlight key use cases for seaweed, and profile selected companies that are currently involved in these applications.

Figure 21: Seaweed products and their benefits

Segment	Examples	Primary function	Key benefits
Additives	Gelatine substitutes, processed meat and dairy	Thickening, emulsifying and stabilising	Natural and vegan-friendly, lower environmental footprint than animal-based alternatives
Animal feed	Livestock feed supplements, aquafeed supplements, pet food additives	Positive immune response and gut health; better digestive process	Improvement in animal health and reduction in methane emissions from livestock
Biofuels	Biodiesel for cars	Source of energy	Replacement for fossil fuels or land-intensive biofuels
Bio-packaging	Packaging, coatings and plastic film for food containers	Marine-safe and compostable plastic molecules	Replaces fossil fuel substances that have a greater environmental footprint
Biostimulants	Seed treatments	Stimulation of plant growth; protection against abiotic stress	Lower environmental footprint than nitrogen fertiliser alternatives; promotes plant health, productivity and soil regeneration
Construction materials	Used for insulation and building bricks	Sustainable housing	Smaller emissions footprint than traditional building materials; improves energy efficiency of buildings
Cosmetics	Anti-ageing moisturisers, toothpaste	Nutrient-rich ingredients and thickening; stabilising and emulsifying properties	Natural and vegan-friendly; supports skin health
Food	Raw salads, crisps, spaghetti, burgers	Source of energy, proteins and vitamins	Supports healthier diets; lower environmental footprint than animal or land-based alternatives
Pharmaceuticals	Gastrointestinal protectors, wound care products, nutrient health supplements	Bioactive and nutrient-rich ingredients	Disease prevention and natural health enhancement
Textiles	Seaweed fibres used in wide range of products including underwear, T-shirts, diapers	Source of clothing	Skin-friendly and environmentally friendly textiles

Source: Seaweed for Europe, Standard Chartered Research

Seaweed can help address malnutrition

Before addressing how seaweed can help address sustainability-related challenges, we outline how these challenges may evolve as a result of demographic shifts taking place globally.

The world's population is likely to continue to grow over the next few decades, increasing sustainability challenges including food production and GHG emissions. The UN estimates that the global population will rise to 10.3bn by 2100 from around 7.9bn in 2022 (Figure 22). UN estimates also indicate that well over 90% of global population growth until 2050 will take place in Africa and Asia. Beyond 2050 the UN estimates that Africa's population will increase by a further 59%, or c.1.5bn people, to 3.9bn by 2100 (Figure 23).

Seaweed to help address undernourishment

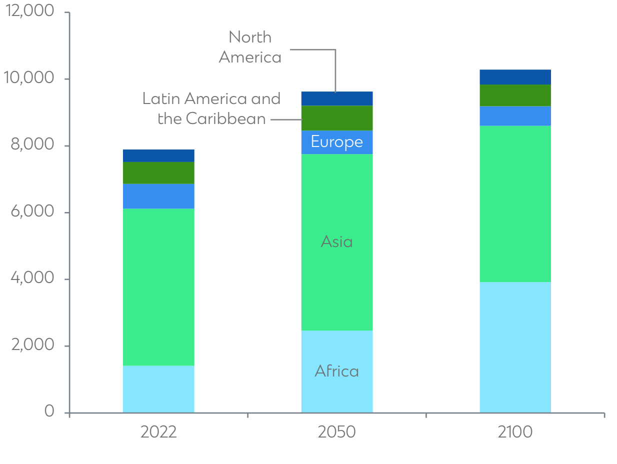
The sustainability challenges created by population growth cannot be overstated, in our view. The number of undernourished people globally is already a key challenge, and several of the SDGs aim to address lack of food availability or consumption. However, progress has been poor – the number of undernourished people globally rose to 735mn, or 9.2% of the global population, in 2022, from c.550mn in 2015, according to the FAO.

Food insecurity, which is closely linked to undernourishment, has also worsened substantially. Almost 61% of Africa's population faced moderate to severe food insecurity as of end-2022, rising from just over 45% in 2015. In Latin America and the Caribbean, almost 38% of people faced food insecurity last year, while the share for Asia was more than 24%.

In the absence of strong action, we expect food insecurity and undernourishment to worsen substantially in Africa and Asia between now and 2050, given that food demand will rise as these regions' combined population expands by a projected c.1.6bn during that period. Global food demand is likely to increase by 50% between 2010 and 2050, according to a 2021 meta-analysis of projections for global food demand and population at risk of hunger (published in Nature by van Dijk et al).

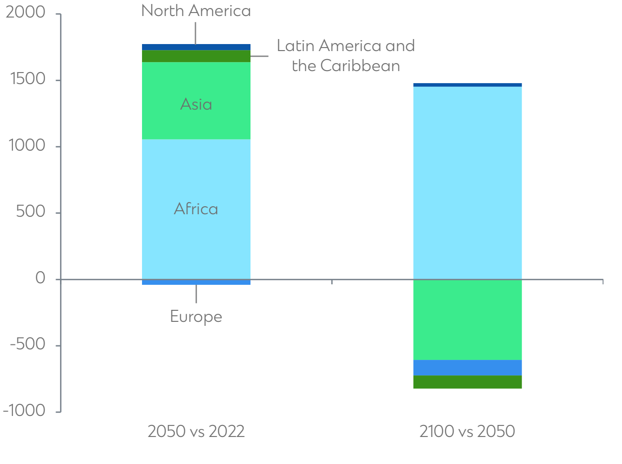
Producing 50% more food while also improving environmental conditions will be extremely challenging unless new food products and technologies are taken up on a large scale. Seaweed can play a significant role here, not least because it can be produced at scale in Asia and Africa – where population growth (and therefore food demand growth) is likely to be the highest in the coming decades.

Figure 22: Global population
bn



Source: United Nations, Standard Chartered Research

Figure 23: Change in population by region
bn



Source: United Nations, Standard Chartered Research

Seaweed to help address obesity

Seaweed may also help to address obesity, the other challenge associated with malnutrition. A growing share of the world's population is either overweight or obese, which has significant health and economic implications.

World Health Organisation (WHO) data on obesity strongly supports the need for action. Some 800mn people globally are obese, and the medical consequences of this will cost the global economy c.USD1tn by 2025, according to WHO. Furthermore, childhood obesity is expected to increase by 60% between now and 2030, resulting in 250mn obese children aged 5-19.

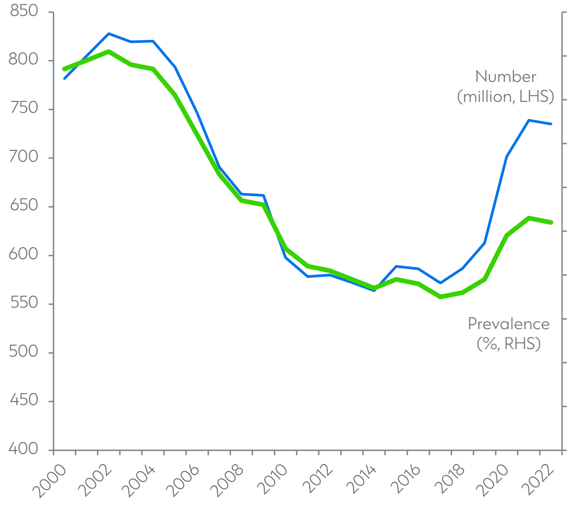
Seaweed typically contains a range of vitamins and minerals that can improve overall health levels. These include vitamins A, B1, B2, C, E and K, calcium, potassium and folate. Given the health benefits of seaweed, its use as a food item can help to address not just overweight and obesity but also broader health issues. Seaweed's health benefits include the following:

- **Improves thyroid function:** Seaweed contains iodine, which is needed for proper thyroid functioning. A well-functioning thyroid helps to maintain a good metabolism.
- **Improves gut health:** Seaweed contains several chemicals that function as prebiotics. These feed healthy bacteria in the digestive tract.
- **Stabilises blood sugar levels:** Brown seaweed contains an antioxidant that may play a role in improving blood sugar control levels, which can in turn reduce the risk of developing type 2 diabetes.

Providing access to healthy and – importantly – affordable food is a key requirement in addressing obesity. Seaweed can be produced in all regions globally, and if production is done on a larger scale, it has the potential to become a healthy food option available to consumers at an affordable price.

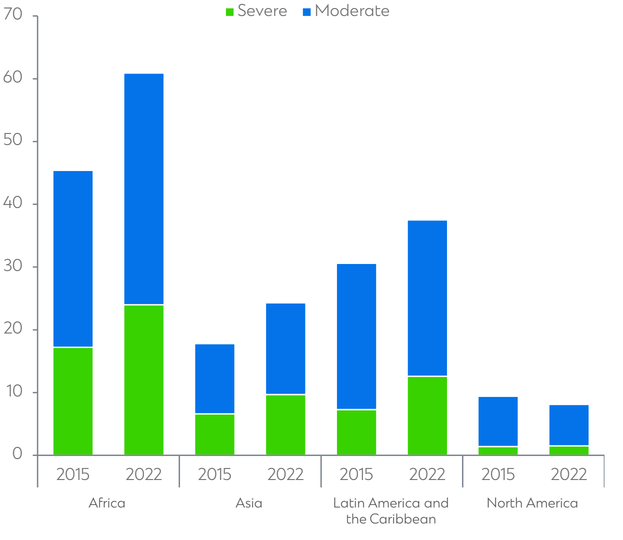
A growing body of research breaks down the chemical composition of seaweed to better understand whether it can be used as a key food ingredient on a larger scale. Protein is one of these relevant macronutrients. A study from Thiviya et al (2022) strongly supports the use of seaweed as a key protein source for a range of food products. With a protein content of up to 40%, they estimate that seaweed is comparable – and in some cases nutritionally superior – to animal-based protein sources. The quality of the protein in seaweed is high, as so-called essential amino acids typically make up 40-50% of the total amino acids found in seaweed. This is similar to the shares found in soya (39%) and egg protein (47%).

Figure 24: Prevalence of undernourishment



Source: FAO, Standard Chartered Research

Figure 25: Food insecurity by region



Source: FAO, Standard Chartered Research

Seaweed applications in food production

Seaweed is used in a number of ways as part of food production. In addition to being consumed directly (for example in soups and salads or as a vegetable), seaweed is also used as a food additive. Three so-called hydrocolloids found in seaweed are used in a variety of food products (shown in Figure 26).

Figure 26: Seaweed used as a food additive

Hydrocolloid	Food product	Function
Agar	Jellies, bakery and dairy, confectionary, canned fish and meat, sauces, soup beverages, pie fillings and icings	• Used for gelling and stabilising characteristics • Used in candies to enhance gel strength • Used in canned products due to high melting temperature • Helps dairy products to have a better texture • Used in beverages as a flocculant and clarifying agent
Alginate	Ready-to-eat soups, sauces, mayonnaise, ice creams, margarine, caramels, desserts, granola bars, yoghurt, juices and beverages	• Used as a gelling, thickening and stabilising agent • Used in canned meat to help with heat transfer • Helps to minimise water loss of food items • Used in pastry to prevent fruit contents from hydrating the cake • Helps to prolong shelf life and product appearance • Alginate helps to smooth texture of ice creams and delay melting
Carrageenan	Canned meat, cooked sliced meat, fruit juices, puddings, ice creams, creams, chocolate milk, milkshakes, pie fillings	• Used for its gelling, stabilising and thickening characteristics • K-carrageenan forms a hard and brittle gel in cake icings • Helps in retention of water and texture in cooked meats • Enables a rise in the viscosity of chocolate milk to keep the chocolate molecules suspended • Used to avoid whey separation while making ice creams, creams and milkshakes

Source: Sultana et al (2022), Standard Chartered Research

Seaweed can also be used in the production of meat- or plant-based products given its nutritional value. It is an ingredient in a wide range of burgers and sausages, as well as in plant-based products such as noodles, bread and pasta (examples are shown in Figure 27).

Figure 27: Seaweed used as food ingredient in meat- and plant-based products

Food product	Seaweed composition content
Meat-based products	
Burgers, pork frankfurters, Restructured poultry steaks	5.6% dried and milled seaweed
Beef patties	40% blanched and blended
Turkey meat sausages	0.04% fucoxanthin extracted from seaweed
Frankfurter sausages	Low-fat frankfurters: 5.5% seaweed Low-fat, low-salt frankfurters: 0-22.6% total seaweed content
Pork patties	0-5% seaweed
Plant-based products	
Wheat flour noodles	>5% dried and milled seaweed
White bread	2-8% seaweed powder
Wholemeal and white wheat flour breadsticks	5-15% air-dried and milled seaweed
Fresh noodles	4-8% seaweed powder
Pasta	10% blended seaweed

Source: Sultana et al (2022), Standard Chartered Research

Side effects of eating seaweed need to be considered

Some uncertainty remains around potential toxicity if seaweed were to be consumed on a larger scale. One of the key issues here relates to seaweed's iodine content and the fact that excessive iodine consumption can affect thyroid function. Another issue relates to potential exposure to heavy metals such as arsenic, aluminium, cadmium and lead. Cherry et al (2019) noted that further research on the side effects of eating seaweed is needed. In addition, disclosure rules need to be developed for the composition of seaweed products; only a small percentage of seaweed products currently on the market provide full disclosure to consumers.

Food-related seaweed demand could increase 12-fold

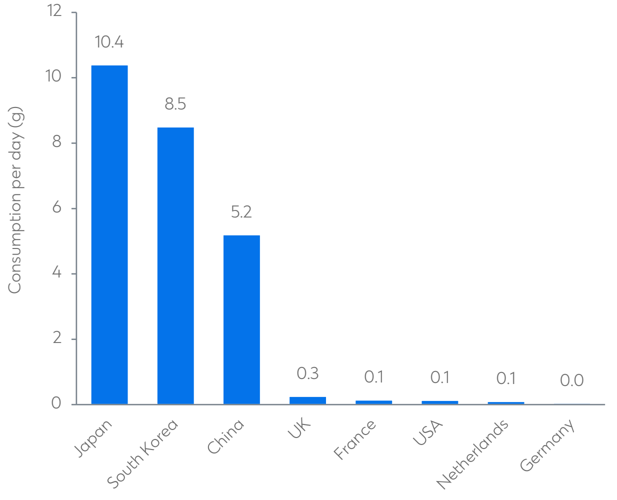
By helping to address both obesity and undernourishment, seaweed could offer a partial solution to the so-called double burden of malnutrition. A campaign focused on the health benefits of eating seaweed may help to increase seaweed consumption – especially outside Asia, where per-capita seaweed consumption has historically been low. Equally, seaweed could be an important food additive in countries and regions facing food insecurity and growing populations. Africa appears to have strong growth potential for seaweed consumption. The region's abundance of marine areas would also provide an opportunity to establish local seaweed industries that could help to revitalise coastal economies.

Per-capita seaweed consumption in key countries in Asia ranges from 5g per day in China (Chen et al, 2018) to just over 10g per day in Japan (Murai et al, 2020). In contrast, seaweed consumption in developed markets including the Netherlands and France is currently less than 1g per day (Vellinga et al, 2022). Based on FAO data on seaweed production, and the fact that close to 90% of global seaweed production is currently used for food consumption, we calculate that average daily per-capita consumption of seaweed globally is less than 1g (Figure 28). To assess the impact of a global increase in seaweed consumption as a food alternative, we have run three scenarios.

- **Low growth:** This scenario assumes that food-related seaweed demand is purely driven by population growth rather than by changes in daily per-capita consumption.
- **Medium growth:** Under this scenario, we expect global per-capita consumption of seaweed to increase to China's current level of 5g/day (which is lower than levels in South Korea or Japan, the largest consumers).
- **High growth:** In this scenario, we assume that global seaweed consumption reaches Japan's current level of c.10g/day. Vellinga et al (2022) suggest that this level would not trigger health-related concerns related to sodium consumption or exposure to cadmium, lead and mercury. Vellinga does conclude that if 10% of certain products such as pasta, bacon or lettuce were replaced with seaweed, further research would be needed to assess the impact on iodine intake and exposure to arsenic.

Using UN population estimates for the next few decades, we calculate total food-related seaweed demand under each of these three scenarios. In the low-growth scenario, we would expect total dry-weight seaweed demand to increase c.20% between now and 2050. In the high-growth scenario, on the other hand, food-related seaweed demand would increase c.12-fold from current levels to 35.1Mt of dry weight per year (Figure 29).

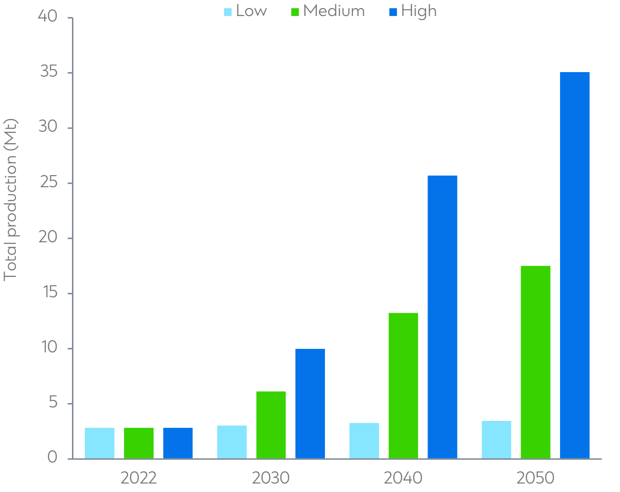
Figure 28: Seaweed consumption per capita



Source: Murai et al, 2020, Chen et al (2018), Vellinga (2022) CBI, Island Institute, United Nations, FAO, Standard Chartered Research

Figure 29: Food-related seaweed demand

Estimates based on low-, medium- and high-growth scenarios



Source: Murai et al, 2020, Chen et al (2018), Vellinga (2022) CBI, Island Institute, United Nations, FAO, Standard Chartered Research

Based on the demand projections in our scenarios, we estimate the total size of seaweed farms that is likely to be needed to produce the required amount of wet seaweed. Based on an average yield of 1,600 tonnes of seaweed per hectare per year (Duarte, 2022) and a wet-to-dry seaweed ratio of 10x, we estimate that almost 11,000 km2 of seaweed farms are needed to meet our 2050 seaweed demand estimate. Producing the amount needed under our high-growth scenario would require almost 22,000 km2 of seaweed farms – meaning that just over 20,000 km2 of new seaweed farm capacity would have to be built between now and 2050.

While these estimates may seem very high, the 22,000 km2 of seaweed farms required under our high-growth scenario would still be only 0.04% of the total ocean space available for seaweed farming. Furthermore, food-related seaweed farming would remain tiny compared to traditional land-based agriculture, which currently occupies almost 50% of total habitable land, or some 48mn km2.

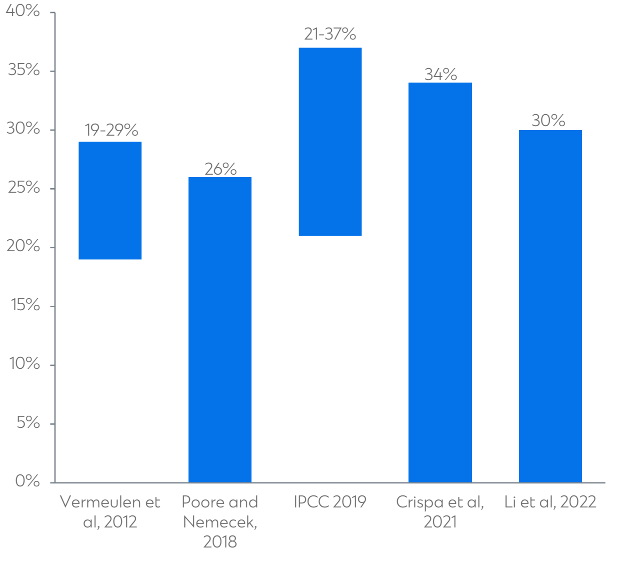
Seaweed as a mitigation strategy for GHG emissions

The expected growth in global food demand over the next few decades is not the only reason why we think seaweed production needs to increase. The unsustainable nature of the current global food system is another.

The global food system plays a key role in the debate on climate change and emissions reduction, as the current food supply chain is estimated to contribute more than 30% of GHG emissions. A 2021 paper from Crippa et al, for example, estimated that food-system emissions in 2015 amounted to 18 gigatonnes of CO_2 equivalent, representing 34% of total GHG emissions. The Intergovernmental Panel on Climate Change (IPCC) has estimated that the emissions associated with the global food system account for 21-37% of overall anthropogenic emissions (Figure 30).

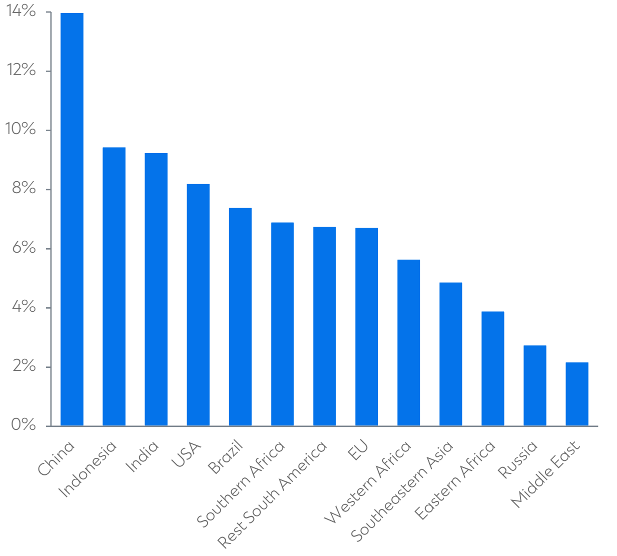
The large share of GHG emissions generated by the current food system is not the most worrying factor, in our view; the likely trend in absolute food-related emissions – especially in the developing world – is a bigger concern. Using Crippa's estimates, we calculate that food system-related emissions increased by 15% in the developing world between 1990 and 2015, versus only 0.7% in the industrialised world. Crippa's data shows that 50% of the world's food-related GHG emissions in 2015 were generated by China, Indonesia, Brazil, India, Russia and Southern Africa.

Figure 30: Contribution of the total food system, to global GHG emissions



Source: Vermeulen et al, Poore and Nemecek, IPCC, Crippa et al, Lie et al, Standard Chartered Research

Figure 31: Contributions to global food-related GHG emissions in 2015, by country/region



Source: Crippa et al, Standard Chartered Research

The future food system versus land, water and emissions intensity

Expected population growth, and the likely further expansion of the middle class in the developing world, are the primary drivers of the expected increase in global food demand between now and 2050. This will put increasing pressure on land use and freshwater consumption, resulting in sharp increases in GHG emissions unless food production and consumption profiles change.

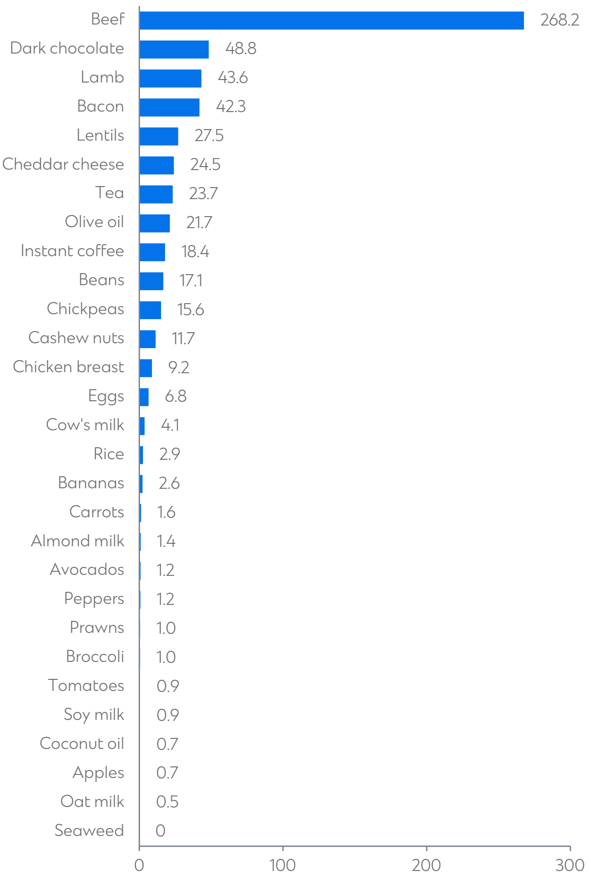
Food production puts a significant strain on the world's freshwater supplies. Agricultural production accounts for almost 70% of freshwater withdrawals, according to the OECD. Meanwhile, FAO data suggests that 50% of habitable land globally is already used for agriculture, with 77% of that amount used for keeping livestock.

The food items with the highest land intensity are mainly animal-based (Figure 32). The amount of water needed to produce 1kg of beef or meat is also high, although this is also true for nuts and related products, rice production and fish farming (Figure 33).

Based on land and water intensity, a shift towards a plant-based diet would clearly help to reduce the need for land and fresh water. Seaweed scores very well from a land and fresh-water use perspective, as its production does not require either (only a minimal amount of land is needed for drying the seaweed).

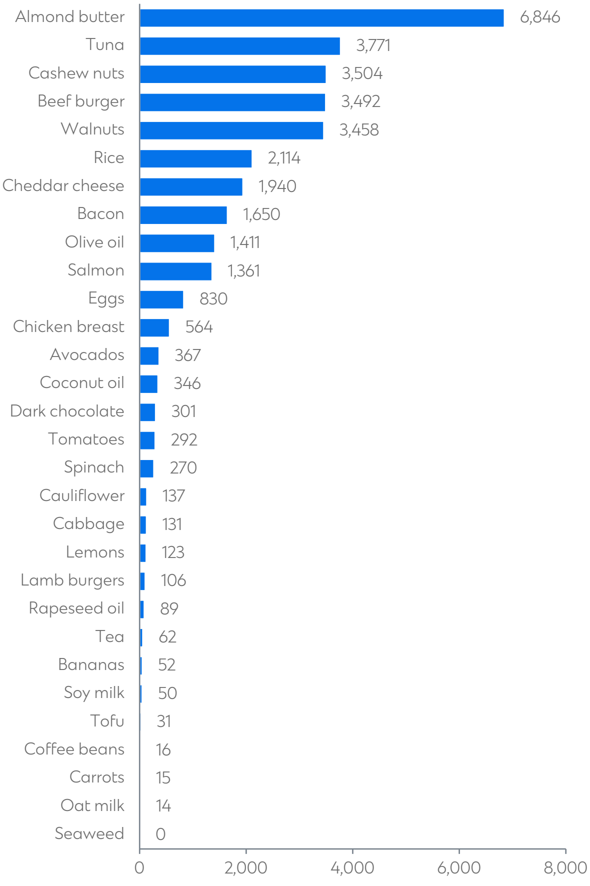
A change in human diets in favour of seaweed would positively impact land use, according to a recent (2023) paper by Spillas et al. Their calculations suggest that every 10% of dietary energy intake directed towards seaweed could spare up to 110mn hectares of land. This land could then be used to feed more people or for carbon sequestration, for example through reforestation.

Figure 32: Land use per kg of produced product
m^2



Source: Poore and Nemecek 2018, Standard Chartered Research

Figure 33: Water withdrawal per kg of product
Litres



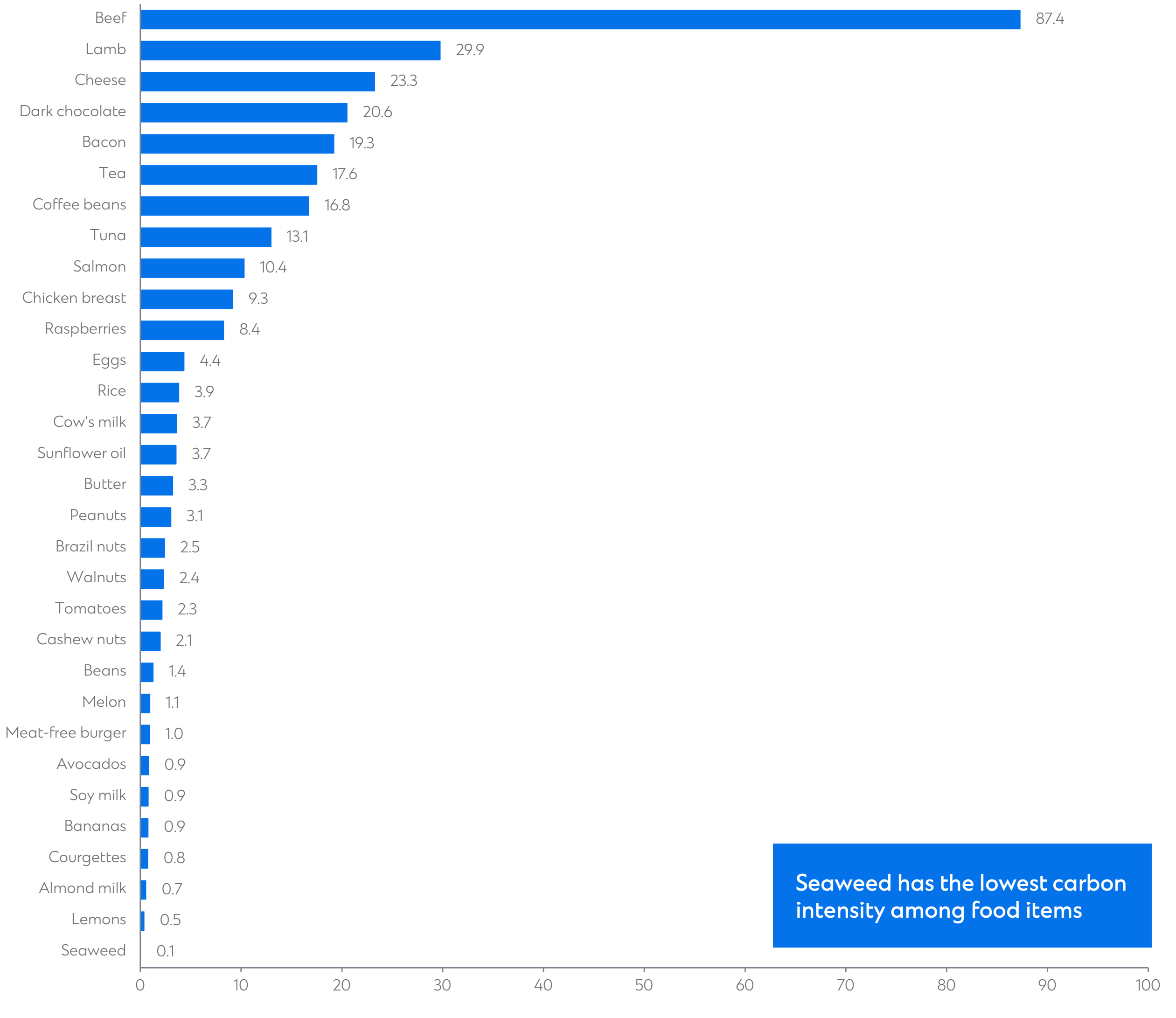
Source: Poore and Nemecek 2018, Standard Chartered Research

Seaweed is also probably the least emissions-intense food item currently produced, in our view (Figure 34). For every 1kg of dry-weight seaweed produced, only 0.13kg of CO_2 is generated, according to studies by Alvarado-Morales et al (2013), Czyrnek-Deletre (2017), Fry et al (2012) and Jung et al (2016). This is far lower than the GHG emissions intensity of other food items, as calculated by Poore and Nemecek. While a more recent estimate (Gephart et al, 2021) puts the emissions intensity of seaweed production higher, at c.1kg of CO_2 equivalent per 1kg of edible weight, this is based on a small sample size of five seaweed farms.

The food industry is becoming more engaged

Given seaweed's small footprint in terms of land/water use and GHG emissions, increased seaweed consumption should be promoted to help achieve long-term climate change and emissions targets. The food industry is increasingly recognising its potential. Industry leaders including Nestlé, Cargill, Procter & Gamble and Danone (among others) have publicly commented on their interest in increasing their exposure to the seaweed industry. This is an encouraging step towards unlocking the sector's growth and sustainability potential, in our view.

Figure 34: Emissions intensity of 1kg of food production
Kg of CO_2 equivalent



Source: Poore and Nemecek (2018), Jones et al (2021), Standard Chartered Research

Biostimulants: Seaweed aids agricultural sustainability

The market for biostimulants is one of the most developed as far as seaweed applications are concerned. Biostimulants are inputs used in agricultural processes to enhance productivity and reduce their environmental impact. Biostimulant use can reduce the use of fertilisers, thereby helping to maintain soil health and reducing the negative impact of fertiliser use on ground water quality. One benefit of biostimulants is that they facilitate nutrient assimilation.

The use of biostimulants can also help plants to cope with the impact of drought, heat, increased salinity, and flooding. A side effect of this is that plants become less vulnerable to diseases. In combination, these effects enhance production yields. The features of biostimulants allow them to be used for agricultural and horticultural purposes.

Seaweed-based products are used in agricultural processes in a number of different ways, including as biofertilisers, soil improvers or plant biostimulants. The range of so-called bioactive components contained in seaweed has been studied for some time. The addition of seaweed to agricultural processes brings benefits including increased crop resistance to adverse environmental issues and oxidative stress, enhanced disease resistance, improved water holding capacity and improved conditions for microbial soil (Figure 35 provides an overview of the impact of seaweed-based biostimulants on a range of food products).

Figure 35: The impact of adding seaweed-based biostimulants to specific food products

Crop	Observed effects	Crop	Observed effects
Tomato	• Increased shoot and root growth • Increased flowering • Fruit yield increase • Fruit quality improvement • Improved resistance to pathogens • Increased tolerance to salinity, drought and cold stress	**Onion**	• Increased germination rate and seedling vigour • Increased bulb diameter and weight • Increased mineral content • Disease reduction caused by downy mildew • Aided in water stress resistance and increased nitrogen, phosphate and kalium uptake
Sweet pepper	• Increased shoot and root growth • Increased flowering • Fruit yield increase • Fruit quality improvement • Increased tolerance to salinity, drought and cold stress	**Potato**	• Growth improvement • Increased yield and tuber quality • Increased resistance to drought stress
Lettuce	• Increased root and shoot • Increased photochemical efficiency • Marketable yield increase	**Cucumber**	• Increased fruit yield • Enhanced nutritional fruit content • Reduced fungal infections by leafspot
Cauliflower	• Increased heart size • Increased curd diameter	**Broccoli**	• Increased biomass • Increased nutritional value
Strawberry	• Increased vegetative growth • Increased yield • Enhanced fruit quality and taste • Increased resistance to powdery mildew, grey mould, and stem and end rot	**Spinach**	• Increased fresh yield, dry biomass and leaf area • Increased micro/macronutrient profile • Increased resistance to drought stress
		Soybean	• Improved nutrient uptake • Enhanced yield parameters • Improved drought tolerance

Source: Ali et al (2021), Standard Chartered Research

Impact of seaweed and biostimulants

Biostimulants have been widely found to increase agricultural yields. A meta-analysis of 180 qualified studies (Li et al, 2022) found that seaweed-based biostimulants generated an average yield increase of 17.1%, the second-largest after plant-based extracts (Figure 36).

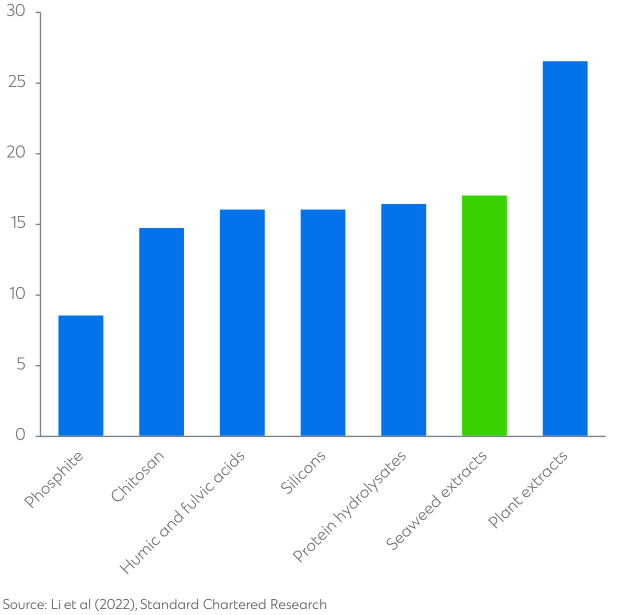
A breakdown of yield improvements by climate underscores the relevance of biostimulant use in emerging economies (Figure 37). Areas that experience warmer and drying conditions benefit more from biostimulant addition than other regions. In desert or steppe conditions, biostimulant use results in a yield increase of around 24-25%, versus 12.6% for fully humid conditions and c.16% for either summer or winter dry regions. This suggests that increasing biostimulant use in the developing world – especially in Asia and Africa – should be a key priority, especially given that food insecurity is also higher in these regions.

Strong growth potential for the seaweed-based biostimulant market

The outlook for the overall biostimulant market is positive, in our view, given a range of structural drivers.

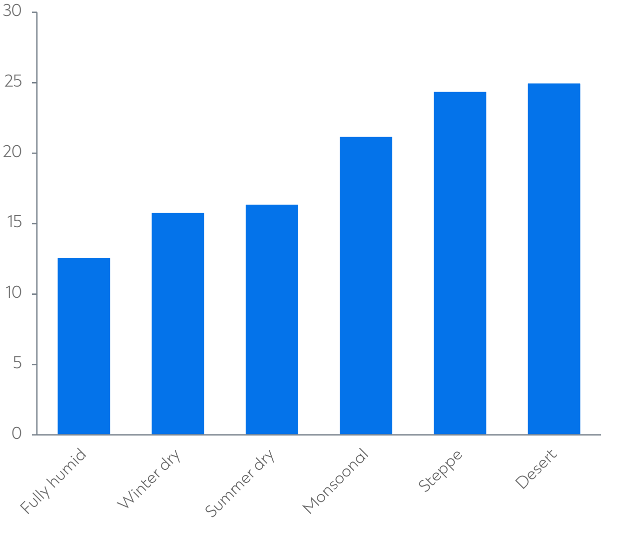
- The expected increase in global food demand over the next few decades, combined with the environmentally intense nature of current agricultural production and the need to reduce GHG emissions, points to strong growth in demand for more sustainable farming solutions, in our view. One of these solutions is to reduce the use of synthetic fertilisers.
- The lack of arable land available for agricultural purposes means that meeting increased food demand will require an improvement in agricultural yields. Biostimulants offer a solution here too.
- Regulation of biostimulants is developing, which should support greater adoption. In the US and the EU, regulations have been adopted that support the use of biostimulants. Programmes such as the EU's 'Farm to Fork' strategy also require farmers to reduce the use of fertilisers and pesticides, further supporting the growth outlook for biostimulants.
- Only 0.4% of Europe's agricultural land is currently treated with biostimulants, according to the Bio4Safe project. Given that seaweed farming is 4x more productive than land-based farming, Bio4Safe highlights that growth prospects for seaweed-based biostimulants should remain strong.

Figure 36: Yield improvement for different biostimulants (%)



Source: Li et al (2022), Standard Chartered Research

Figure 37: Yield improvement from biostimulants, by climate type (%)



Source: Li et al (2022), Standard Chartered Research

The size of the global biostimulant market reached an estimated USD3-4bn in 2022, and European companies accounted for roughly half the market, according to the European Biostimulants Industry Council. It noted that growth in the global market is likely to average 10-12% over the next few years.

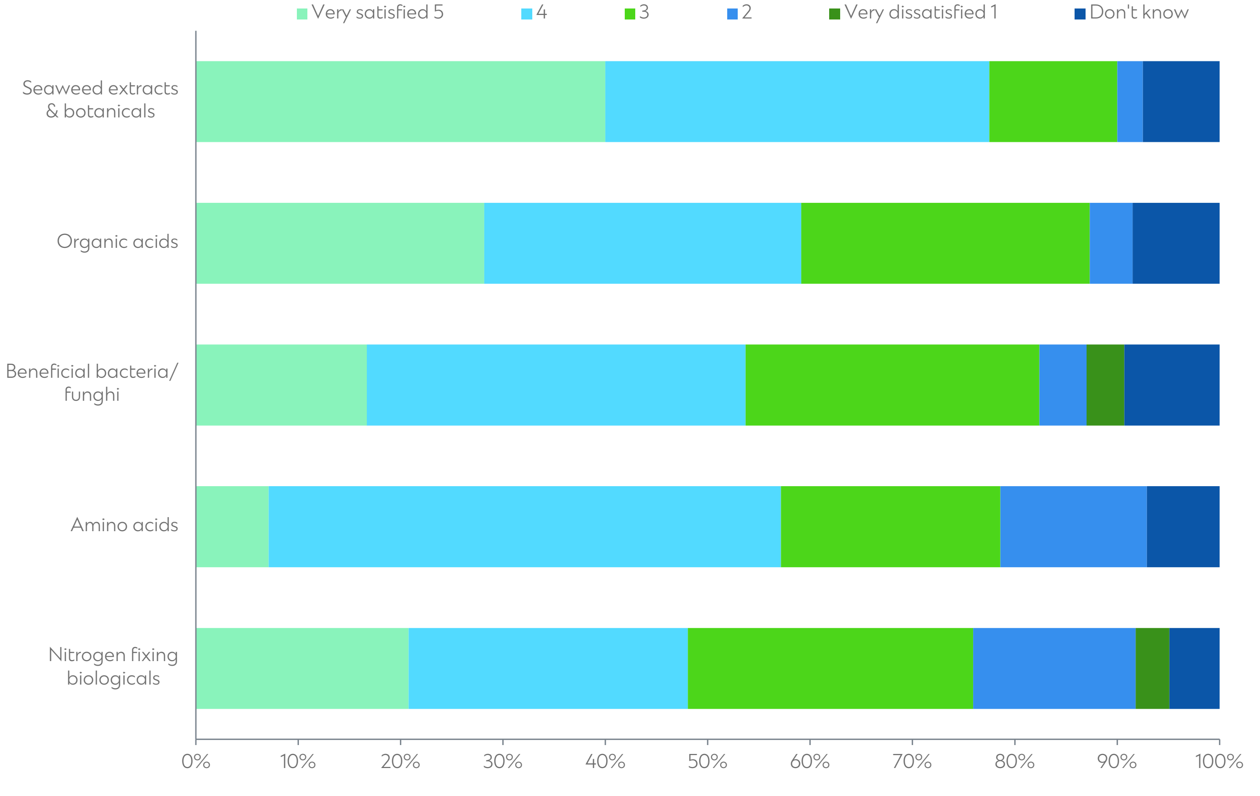
Seaweed-based products make up c.40% of the global biostimulant market, according to the World Bank. We expect the growth outlook for seaweed-based biostimulants to be higher than for the overall biostimulant market given seaweed's superior sustainability characteristics compared to alternatives.

Our conversations with industry participants across all key seaweed end markets consistently point to three hurdles to growth in the industry: (1) a lack of access to financing, (2) regulatory uncertainty, and (3) a lack of seaweed production. This appears to be a classic 'chicken and egg' phenomenon, where raising production depends on increased funding availability, and vice versa.

We believe that potential production growth in the biostimulant market is strong enough to attract outside capital. A 2022 McKinsey survey of 1,354 farmers in the US indicated that just 6% of small and medium-sized farms currently use biostimulants; among large-scale farms (more than 5,000 acres), only 12% use them. Even if farmers use biostimulants, this does not necessarily mean that they use them on all of their land or to maximum effect. Only 0.4% of European agricultural land is treated with biostimulants, according to the North Sea Farmers Association, even though Europe makes up 50% of the global biostimulant market.

Seaweed's sustainable characteristics suggest that growth in the market for seaweed-based biostimulant extracts may exceed overall biostimulant market growth (which is widely estimated at around 10% going forward). According to a 2022 survey of biostimulant users by Stratus AG, almost 80% of those that used seaweed extracts were satisfied or very satisfied with the product. This was a higher rate of satisfaction than for all other surveyed biostimulants (Figure 38).

Figure 38: Satisfaction with biostimulants used in 2022



Source: Stratus AG Research, Standard Chartered Research

A 10% per annum growth rate for biostimulants appears feasible, as it would lift the share of European agricultural land treated with biostimulants to 0.84% by 2030 and 2.2% in 2040 (from 0.4% currently). Agricultural usage of biostimulants is lower outside Europe, suggesting greater upside in other regions. A 10% growth rate for the biostimulant market would, all else being equal, increase the market's value from c.USD3.5bn currently to USD7.4bn by 2030 and USD19bn by 2040.

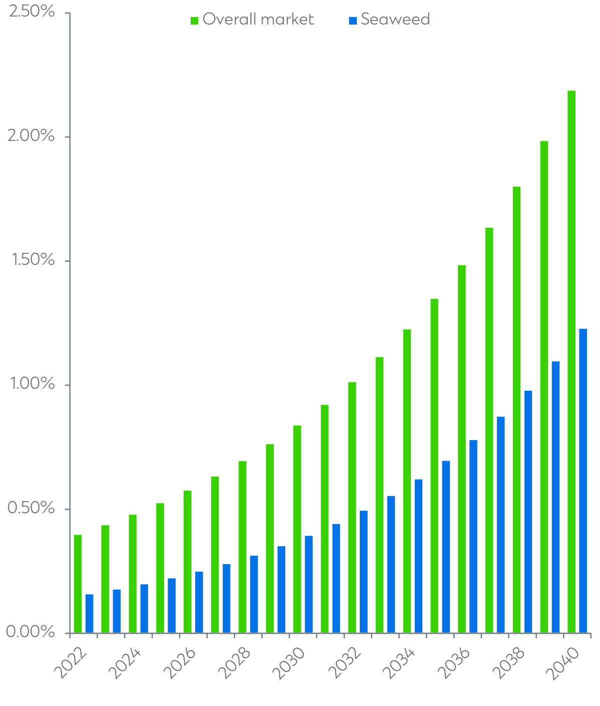
Assuming that the market for seaweed-based biostimulants grows at 12% per annum, we expect their share of the total biostimulant market to increase from c.40% today to 56% by 2040. On these growth estimates, the value of the seaweed-related biostimulant market could increase from c.USD1.4bn in 2022 to USD3.5bn by 2030 and USD10.8bn by 2040.

Our estimates for the potential value of the seaweed-based biostimulant market do not incorporate price changes. The use of biostimulants typically reduces farmers' need for fertilisers and increases their yields. These gains may exceed the cost of biostimulants; we therefore do not believe that a decline in the price of seaweed-based biostimulants is necessarily needed to drive demand higher.

In May 2020, Farmers Weekly (a UK magazine) highlighted a farmer whose fertiliser cost had fallen to GBP 12 per hectare – GBP 75 per hectare below the UK average – and whose yield had increased by up to 5%, or 0.47 tonne of additional wheat per hectare, after starting to use biostimulants. These gains more than offset the biostimulant cost of up to GBP 12 per hectare.

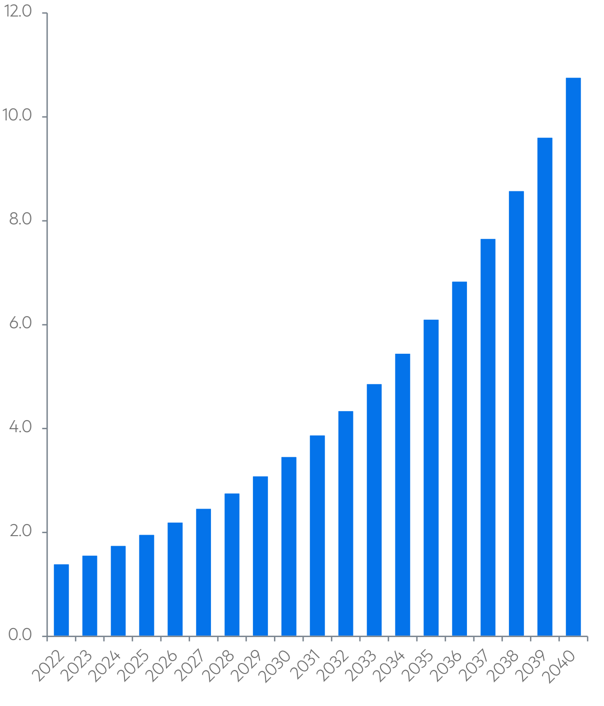
Highlighting the potentially disruptive impact of biostimulants, Evonik Industries is trialling a biostimulant that allows farmers to reduce their fertiliser use by 50% while maintaining 93% of their yields. Relatively high fertiliser costs (especially since the start of the Ukraine war), coupled with the negative environmental effects of fertilisers, are clear supporting factors for biostimulant use, in our view. This should be particularly positive for seaweed-based biostimulants.

Figure 39: Share of European agricultural land treated with biostimulants



Source: World Bank, Bio4Safe, Standard Chartered Research

Figure 40: Potential value of the biostimulant market (USDbn)



Source: World Bank, Standard Chartered Research

Company profile:

The Seaweed Company

Overview

The Seaweed Company was founded in 2018 and is headquartered in the Netherlands. The company has seaweed farms located in Europe, Morocco and India. Shareholders include Belgian retailer Colruyt, which owns c.20%.

Relevance to the seaweed industry

The stated mission of the Seaweed Company is to develop seaweed-based solutions that make the food system more sustainable and create healthier food options. At present, the company has two areas of focus:

- **Biostimulants:** The Seaweed Company produces seaweed-based biostimulants that it claims can replace 25% of synthetic fertiliser inputs. This benefits soil and water quality, as well as indirectly lowering emissions associated with the production of synthetic fertiliser, according to the company.
- **Meat alternatives:** The Seaweed Company's SeaMeat® product allows meat producers to replace 25% of beef with edible seaweed. This reduces the emissions intensity of an average burger by c.25% and lowers water consumption by c.1,800 litres per kilogramme of burger meat, according to the company. Meat containing SeaMeat® also benefits from a 35% reduction in salt use, increased fibre content and a 51% reduction in saturated fat content.

The Seaweed Company's products are likely to generate interest from food companies. Switching to the company's products would help to decarbonise the food system and as a result lower Scope-3 emissions for food companies.

The Seaweed Company has a vertically integrated operating model. Recent strategic agreements with companies such as Colruyt and Jorda Food Group are examples of this, in our view. Nevertheless, scaling up production capabilities sufficiently is a key challenge for most (often small) seaweed-exposed companies. To address this issue, The Seaweed Company – with the help of several strategic partners – is developing scalable production units that should allow it to expand its number of farms, increase production capacity, and expand to new geographical locations.

To broaden its production base, the company has established an agreement with local governments in India under which it trains seaweed farmers. The programme is funded by local governments and provides The Seaweed Company with a guaranteed seaweed supply while supporting coastal communities.

The Seaweed Company's view on the seaweed market

The Seaweed Company believes that growth potential is strongest for end markets with a more limited cost premium for seaweed-based products. These include food ingredients, biostimulants and health-focused seaweed applications.

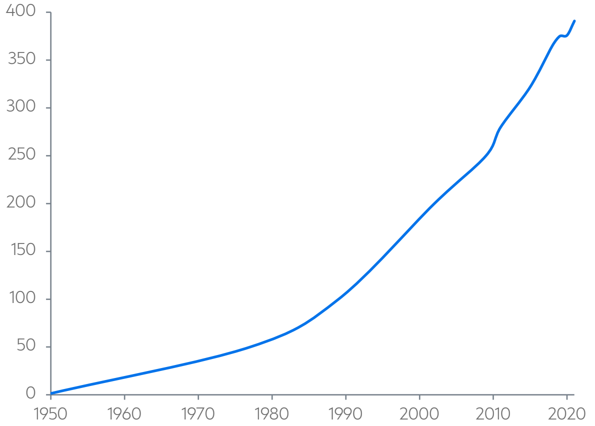
To unlock the industry's growth potential, the company believes that greater standardisation of regulation across geographies and increased government support for seaweed (e.g., subsidies) would be needed.

Bioplastics as a long-term seaweed opportunity

Bioplastics are another potential future end market for seaweed. Some 390Mt of plastic is currently produced annually; virtually all of this is petroleum-based, leading to GHG emissions (Figures 41-42).

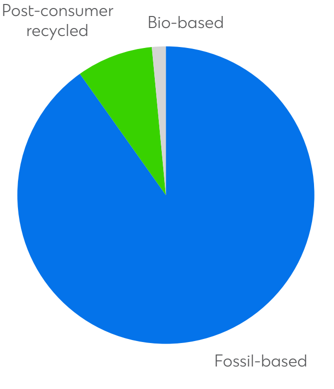
Bioplastics are materials based on organic matter including seaweed; they currently represent just c.1% of the global plastic market. Considering the rapid increase in plastic use, the non-degradable nature of plastic, and the lack of sustainable waste solutions for plastic, there is a growing need for alternatives (especially to single-use plastic).

Figure 41: Plastic production over time
Million tonnes



Source: Plastics Europe, Standard Chartered Research

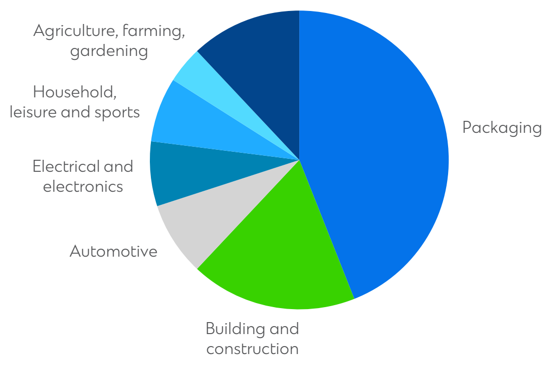
Figure 42: Breakdown of plastic by type
Share of total global production, 2021



Source: Plastics Europe, Standard Chartered Research

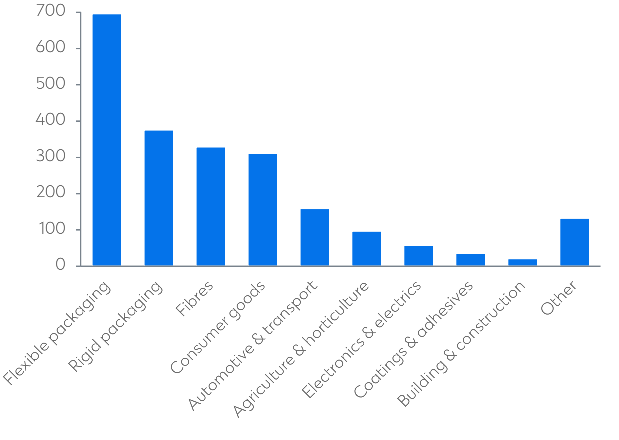
Although plastic is used across a wide range of end markets, a few dominate (Figure 43). Packaging makes up 44% of global plastic demand; almost all of it is in the form of single-use plastics. The recycling rate for plastic is relatively low, at less than 9%, according to Plastics Europe. Bioplastics have a similar end-use profile to traditional plastic, with packaging accounting for c.48% of total production capacity (Figure 44).

Figure 43: Plastic use by market segment
Share of total global plastic use, 2021



Source: Plastic Europe, Standard Chartered Research

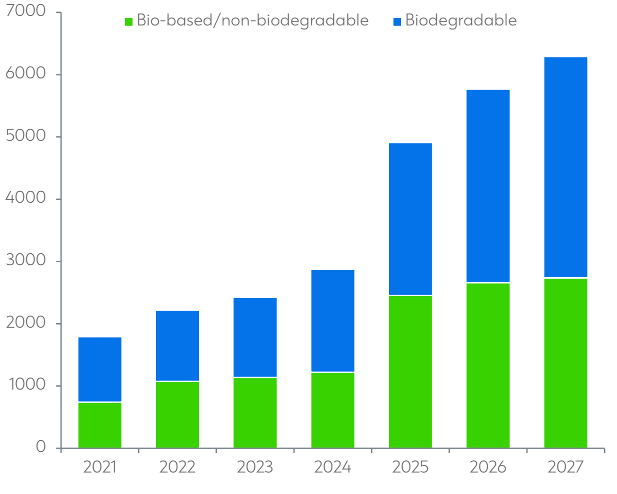
Figure 44: Bioplastics – global production capacity by type (Thousand tonnes, 2022)



Source: European Bioplastics, Nova-institute, Standard Chartered Research

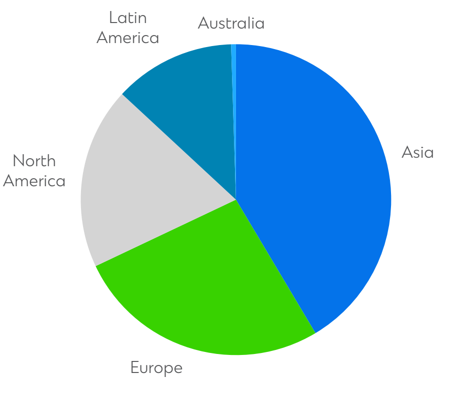
The growth outlook for the bioplastics market is strong. Estimates from European Bioplastics and the Nova Institute indicate that total bioplastic-related production capacity will increase by 184% between 2022 and 2027. Biodegradable bioplastic capacity is projected to increase by 211%, and non-biodegradable bioplastic capacity by 154%. More than 41% of current bioplastics production is based in Asia; Europe accounts for 26.5%, North America for 19% and Latin America for 13%. European Bioplastics estimates that Asia's share will increase to 63% by 2027. Based on total global capacity estimates for 2022 and 2027, this suggests that 75% of new production capacity will be built in Asia.

Figure 45: Production capacity outlook for bioplastics (Million tonnes)



Source: European Bioplastics, Nova-institute, Standard Chartered Research

Figure 46: Bioplastic production capacity by region
Share of total, %



Source: European Bioplastics, Standard Chartered Research

Seaweed as a bioplastic alternative

Seaweed has attracted interest as a bioplastic alternative because it contains biopolymers, which can form viscous dispersions or gels in water and be used to form a film-like material for coatings in packaging.

Seaweed species used in bioplastic production include various types of red and brown seaweed. The characteristics of the polysaccharides differ between seaweed species, allowing them to be used for different end-market applications. For example, biodegradable films and packaging are currently the prime focus for seaweed-based bioplastics. This includes edible films too. Other potential uses for seaweed bioplastics include production of plastic pellets.

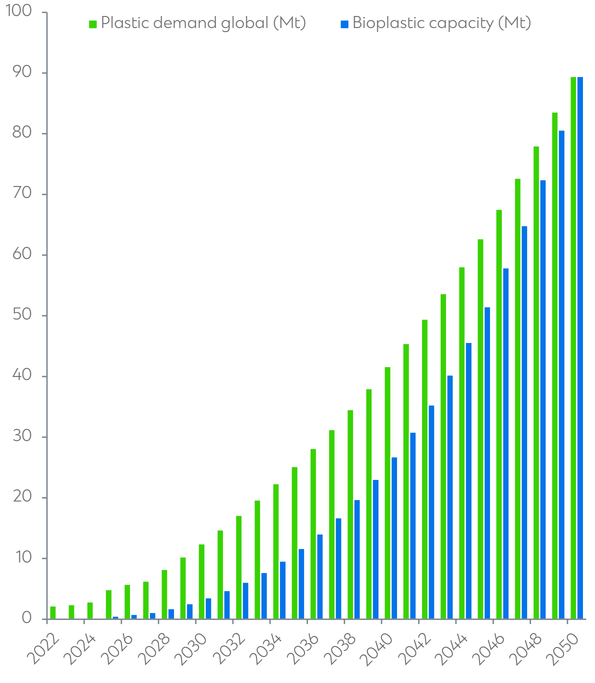
The demand outlook for seaweed as a bioplastic alternative is attractive, in our view. Not only is demand for bioplastics in general growing, but seaweed's sustainable characteristics make it an attractive alternative for companies aiming to improve their sustainability credentials. Key to adoption, however, will be increasing production volumes fast enough to create the necessary economies of scale to make seaweed-related bioplastic products more price-competitive. Our conversations with industry players suggest that seaweed-based bioplastics are currently substantially more expensive than traditional plastic products. This will have to change in order to achieve large-scale adoption, in our view. Government support is another pathway to scaling up adoption; this could take the form of subsidies, or taxation or regulation of traditional plastic products.

We have run a simple scenario to provide an indication of the growth potential of seaweed as a bioplastic alternative. Assuming that plastic consumption growth continues at the 3% annual rate recorded from 2015-21, and assuming a long-term market share of 10% (of the total plastic market) for bioplastics, we calculate that bioplastic production will reach 12.4Mt by 2030, 41.6Mt by 2040, and more than 89Mt by 2050.

Assuming that seaweed production capacity can be scaled up, we believe that seaweed-based bioplastics could achieve a 10% share of the bioplastics market by 2050. Using a 10:1 wet-to-dry seaweed ratio, this would require 3.6Mt of seaweed production annually by 2030, growing to 26.8Mt by 2040 and almost 90Mt by 2050. This compares to current global annual wet seaweed production of c.36Mt. Based on a seaweed price of USD500 per tonne of fresh seaweed, we calculate that the seaweed bioplastics market could reach a value of USD1.8bn by 2030, rising to USD45bn by 2050.

Figure 47: Biocapacity development

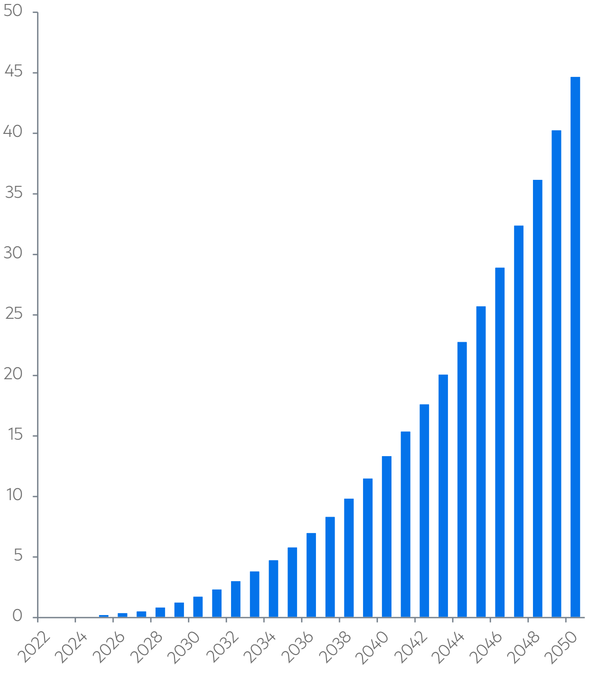
Assuming a 2050 market share for bioplastics of 10%



Source: European Plastics, European Bioplastics, Standard Chartered Research

Figure 48: Value of the bioplastic seaweed market

USDbn



Source: Standard Chartered Research

Company profile:

Notpla

Overview

Notpla, short for 'not plastic', was established in 2019 with the aim of disrupting the single-use plastic and packaging market. The company is working with companies such as Decathlon and Just Eat; it raised its seed round in 2019 with Series A fundraising in 2021. To date, the company has raised GBP 14mn in external financing.

Relevance to the seaweed industry

Notpla's plastic and packaging alternatives use a variety of seaweed species as key ingredients. The company claims that its products biodegrade in four to six weeks, while plastic products do not degrade for more than 100 years and cause micro-plastic issues on land and especially in the oceans.

Notpla's products include Notpla Ooho, an edible bubble designed to replace single-use plastic packaging for liquids. Use cases include the replacement of plastic cups and bottles at sporting events. Other products include the more recent launch of Notpla Coating, a fully biodegradable coating used in food packaging including takeaway boxes.

Notpla has experienced strong growth during the past few years. The company's products replaced 0.6mn units of single-use plastic in 2021 and 2mn in 2022, and it expects this to increase to 10mn in 2023. The company plans to widen its product offering further through the introduction of flexible films for food and food ingredients and seaweed-based paper.

Notpla's view on the seaweed market

Notpla is positive on growth potential for the seaweed market, including seaweed-based products used as alternatives to traditional plastics. It expects tightening regulation of plastic to drive demand for plastic alternatives. For example, the EU's Single-Use Plastic Directive includes outright bans on some single-use plastic items for which non-plastic alternatives are available. Starting in October 2023, a range of polluting single-use plastics are also banned in the UK. Notpla believes that the market potential is significant, and that it would be feasible for the company to capture a 7% share of the bioplastics market.

Seaweed may help to reduce methane emissions

Seaweed's potential to significantly reduce methane emissions from beef and dairy cattle has attracted strong interest. While methane is a short-lived greenhouse gas, its impact on global warming is typically estimated to be almost 30x higher than that of CO2. Furthermore, almost a third of methane emissions are attributed to enteric fermentation from livestock, which can be reduced by adding seaweed to their feed. Seaweed reduces methane output from ruminants in several ways, including by inhibiting an enzyme in the cow's digestive system that ultimately produces hydrogen that is converted into methane.

A growing body of research suggests that adding seaweed to feed products could dramatically reduce methane output from cows. Studies have shown significant results: just 2% of specific seaweed species in a cattle diet could reduce methane emissions by 99% (Machado et al, 2016), and supplementing red seaweed could reduce livestock-related methane emissions by 82% (Roque et al, 2019).

Red seaweed species have recently been recognised as a potential methane reducer in livestock. However, challenges remain, including the fact that the red seaweed must be fed daily. In addition, questions remain about the potential for toxicological effects to be excreted in milk (Muizelaar et al, 2021).

Figure 49: Methane reduction results from adding seaweed to animal feed

Seaweed used	Reduction observed	Seaweed share addition	Source
Red seaweed	95%	5%	Roque et al, 2016
Red seaweed	67%	1%	Roque et al, 2016
Red seaweed	40%	0.10%	Kinley et al, 2014
Red seaweed	98%	0.20%	Kinley et al, 2014
Brown seaweed	92%		Machado et al, 2014
Red seaweed	99%		Machado et al, 2014
Green seaweed	66%		Machado et al, 2014

Source: Roque et al, Kinley et al, Machado et al, Standard Chartered Research

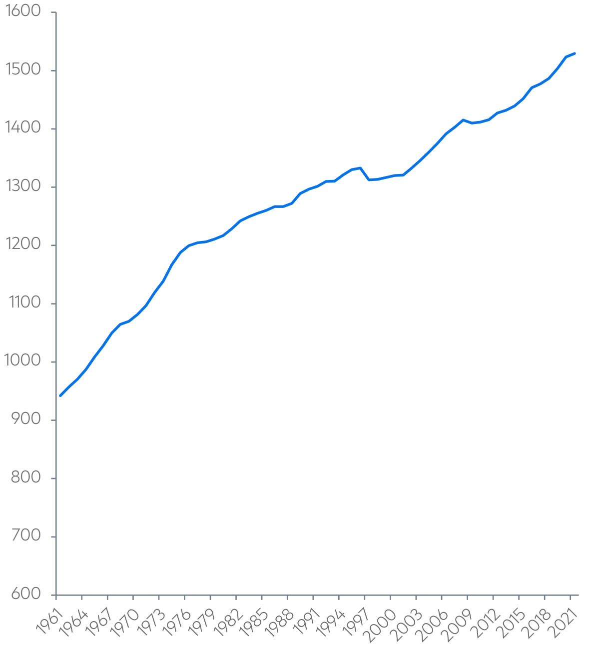
The significant reductions in methane production shown in Figure 49 are not universally accepted. For example, a study by the University of New England using the asparagopsis species of red seaweed showed methane reductions as low as 28%; another by the Swedish University of Agricultural Sciences, also using asparagopsis, reported a 44% reduction. In addition, most of the studies done so far have been in vitro or laboratory-based rather than based on real-world conditions. The degree of methane reduction therefore remains uncertain.

Assuming seaweed does have strong methane reduction capacity, we have calculated that 58Mt of seaweed would need to be produced by 2050 to meet demand for seaweed as a methane-reducing feed ingredient; this is 160% greater than the current global seaweed market. This estimate is based on our estimates of the global cattle population (shown in in Figure 50), the share of cattle that will receive seaweed-based feed, and the required daily intake. The global cattle population increased to over 1.5bn in 2021 from c.940mn in 1961, although the growth rate has slowed to less than 1% annually over the past decade. For our scenario analysis, we focus on 15 middle- and high-income countries with the largest cattle populations (totalling almost 900mn), as we think they are more likely to add seaweed to animal feed than other countries. Considering that most of these are developed economies, and given growing environmental concerns around cattle-related emissions, we assume no further growth in the cattle population in these countries.

We assume that c.30% of cattle will have seaweed added to their feed by 2050 (Figure 51). Academic studies suggest that adding c.0.4% of dry-weight seaweed per kilogramme of feed is sufficient. We use this, combined with average daily feed intake of 10kg per cow, to calculate total seaweed additive needs over time. We use a wet-to-dry seaweed ratio of 15 (Jia et al, 2022) to arrive at our 58Mt estimate for the amount of wet or fresh seaweed that needs to be produced by 2050 to meet this demand (Figure 51). Given the role that reducing methane emissions can play in reducing GHG emissions, our 30% seaweed penetration assumption by 2050 might prove too pessimistic. In that case, seaweed production requirements could rise well beyond our base case.

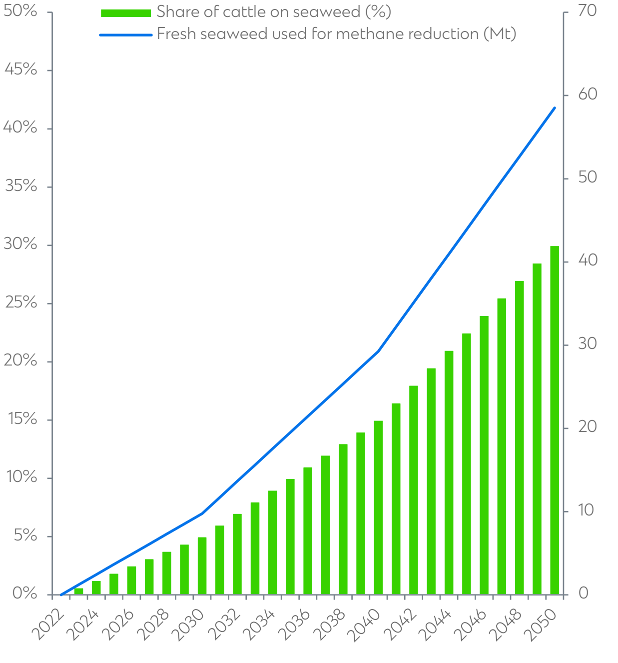
According to our conversations with industry participants, a potential limiting factor for the seaweed-related methane reduction market is that only a very limited set of seaweed species has been identified for this application.

Figure 50: Global cattle population size
Mn



Source: FAO, Standard Chartered Research

Figure 51: Seaweed needed for methane reduction feed (Base-case scenario)



Source: FAO, World Bank, Standard Chartered Research

Company profile:

Sea Forest

Overview

Sea Forest is a Tasmania-based seaweed company that was founded in 2018 by Sam Elsom and Stephen Turner. The company has attracted c.USD30mn in investments to date.

Relevance to the seaweed industry

Sea Forest farms asparagopsis seaweed, the key ingredient in SeaFeed™, a methane reduction animal feed supplement. Methane is one of the largest contributors to GHG emissions and has c.28 times the warming effect of CO2. The reduction of methane in the atmosphere is therefore seen as one of the most effective short-term ways to address global warming.

Since 2018, Sea Forest has developed a c.1,800 hectare marine-based farm off the coast of Tasmania, as well as land-based ponds. Using horizontal and vertical farming techniques, the company currently has 2mn doses of its methane-reducing product at hand, with an ability to double that to 4mn.

Sea Forest notes that it has reduced its cost of production by c.65% since launch and expects to be able to sell its product at a cost of EUR 0.30 per head per day. This would yield a carbon credit for farmers (assuming a carbon price of EUR 50/tonne) of EUR 0.35 per day, making Sea Forest's product cost-effective.

Sea Forest is currently working with several stakeholders across the supply chain, including retailers and cattle farmers. The objective is to create more clarity on the methane reduction that is achieved in real-life conditions. The company notes that a 67% methane abatement has been achieved using SeaFeed™.

Over the next few years, Sea Forest expects a strong increase in the efficacy of its products, and plans to open facilities in new markets. In addition to its methane-reducing product, the company is providing water ecosystem restoration services and exploring a potential expansion into the seaweed-based bioplastics market.

Sea Forest's view on the seaweed market

Sea Forest has a positive view on the growth potential for the overall seaweed market and its methane-reduction product. Key challenges cited by the company include the lack of regulation. For example, farmers in Europe use methane-reducing animal supplements, but they (and retailers) are prohibited under EU law from making methane reduction claims. Sea Forest expects strong consumer appetite to drive demand for its product. Data from a large burger chain in Australia indicates that 35% of its customers opted for more expensive burgers that were produced using Sea Forest's product (Sea Forest had expected this share to be only 5%).

Seaweed: A sustainable ingredient for animal feed

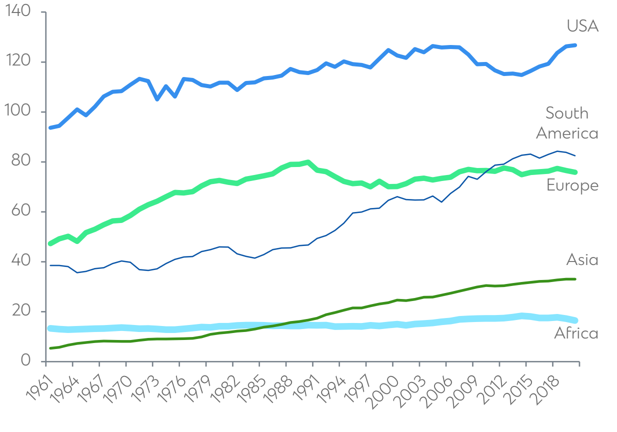
Animal feed is another end market where seaweed can play a role. Demand for animal feed is likely to continue to grow as the world's population increases, and as the expanding middle class in the developing world increases its per-capita meat consumption. We estimate that global meat (beef, chicken and pork) consumption will more than double between 2022 and 2050 to 632bn kg per year. All else being equal, this implies that demand for animal feed will also more than double over the same period, creating significant growth potential for seaweed as a feed ingredient. Our calculations suggest that the market for seaweed as an animal feed additive, which is minimal in size today, could be worth USD1.2bn by 2030 and USD6.4bn by 2050.

In developed markets such as Europe and the US, data shows no meaningful change in per-capita meat consumption in the past 10 years, suggesting that increased awareness of the environmental impact of animals has not caused a significant change in consumer behaviour (Figure 52). Meanwhile, Asia has seen a steady increase in per-capita meat consumption, which has risen 34% since 2000 to 33kg per year. This is still less than half the European level (76kg/year) and almost 75% below the US level (127kg/year), according to the FAO.

Based on estimates of future per-capita meat consumption and population growth, we calculate the increase in animal feed required to meet that demand. We assume that meat consumption in Africa will reach Asia's current levels, and that Asia's per-capita consumption will increase to current European levels by 2050. We assume no change in consumption in Europe and the US, while we expect South America's meat consumption to increase slightly to 100kg per year from 83kg currently. These estimates, combined with UN population growth estimates, underpin our view that global meat consumption will more than double by 2050.

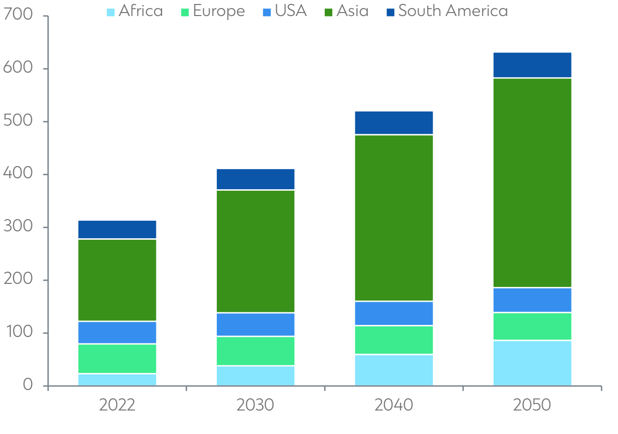
A range of studies have shown that seaweed has several positive effects on animals when used as part of their feed. In addition to being used as a protein additive, seaweed is associated with improved milk hygiene in cows, improved pork quality, and increased egg production and quality in poultry. Seaweed can also be used as aquafeed, with additional reported benefits to fish growth rates and immune systems. The improvement in immune systems is often linked to better feed conversion ratios, which in turn leads to reduced energy expenditure or carbon footprint.

Figure 52: Per-capita meat consumption
Kg/year



Source: FAO, Standard Chartered Research

Figure 53: Potential increase in global meat consumption (Kg bn)



Source: FAO, UN, Standard Chartered Research

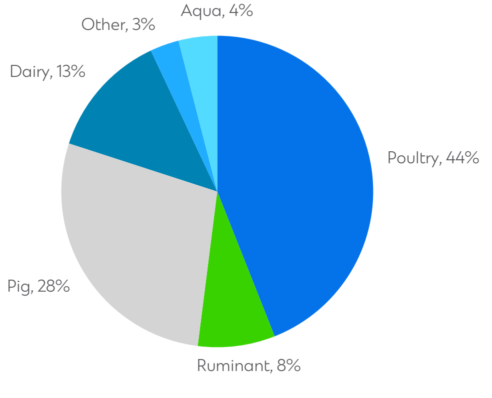
Despite the range of benefits, we note that several challenges may limit seaweed's growth potential as a feed ingredient. For example, the production cost of seaweed is likely to remain higher than that of traditionally used soy-based products, at least in the short term. (We would expect this to change as economies of scale for seaweed improve with increased production capacity; furthermore, the lack of available new arable land may limit the upside for soy production, supporting a switch to alternatives including seaweed). Another challenge is competition from other animal feed alternatives, such as insects or bacteria, as their protein content is similar to or better than that of seaweed.

The market opportunity for seaweed as an animal feed additive is strong, in our view. The global commercial feed manufacturing industry produced 1.2bn tonnes of animal feed in 2021, with revenues of over USD400bn, according to data from the International Feed Industry Federation (IFIF). The 144 largest animal feed manufacturers comprised 42% of this, according to the WATT Global Media database.

We have run a simple scenario to outline the potential size of the seaweed-based animal feed market. Of the total animal feed applied in 2020, poultry accounted for 44%, followed by 28% for pigs, according to IFIF data. Fish farming or aquaculture consumed 4% of total animal feed. We assume that the world's poultry population will increase by 3% annually, while we assume growth rates of 2% for pigs and ruminants and 5% for fish farming. Our assumptions reflect a gradual shift in animal protein consumption towards leaner and less environmentally intense animals and away from cattle and pigs. Our assumptions indicate that total feed demand related to poultry, pigs, ruminant and fish will increase from 984Mt in 2020 to 1.3bn in 2030 and 2.2bn tonnes in 2050 (Figure 55).

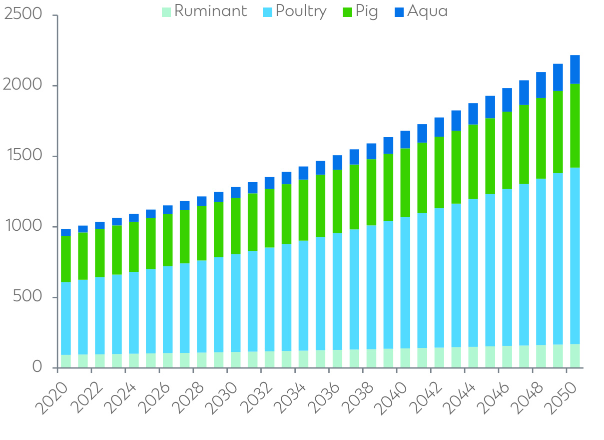
The amount of seaweed added to animal feed ranges from c.3% for pigs to 5% for poultry and fish, according to various studies. Based on these assumptions, we calculate that 18mn kg of dry seaweed additive will be needed by 2030 to meet demand, rising to 96mn kg by 2050. Assuming that 1 tonne of fresh or wet seaweed is needed to produce 7.5kg of dry seaweed additive (World Bank, 2023), we calculate that 2.4Mt of seaweed needs to be produced by 2030 to meet feed demand, rising to 12.8Mt by 2050. Based on a USD500/tonne price for fresh seaweed, we calculate that the market for seaweed as an animal feed additive could be worth USD1.2bn by 2030 and USD6.4bn by 2050.

Figure 54: Feed consumption by category
2020



Source: IFIF, Standard Chartered Research

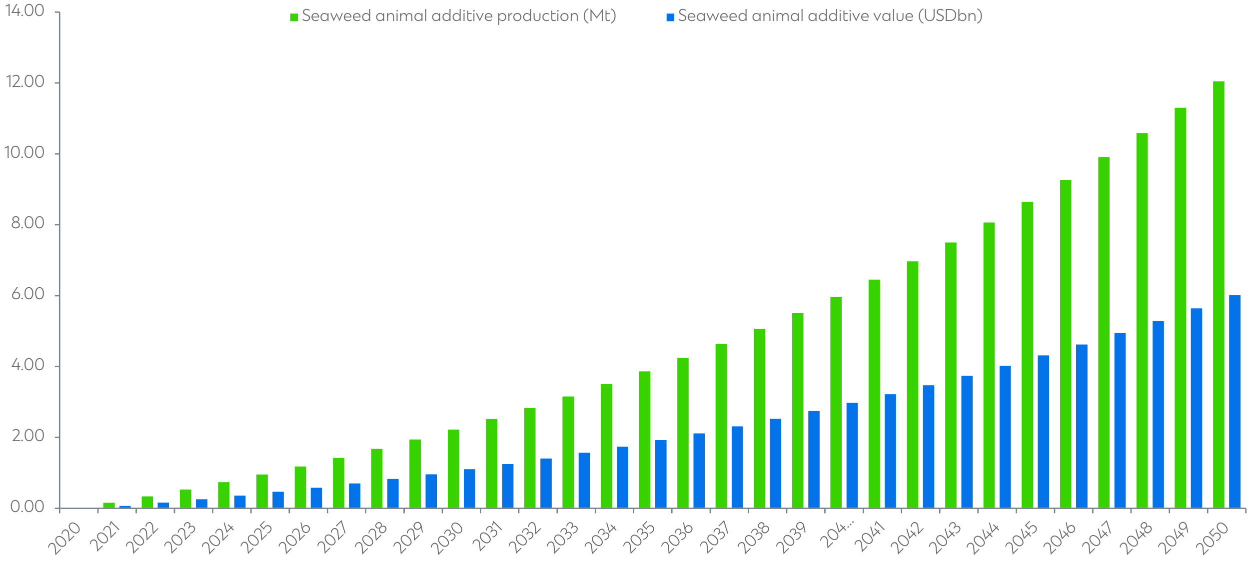
Figure 55: Feed demand development
Million tonnes



Source: IFIF, World Bank, Standard Chartered Research

Considering the potential expansion of the seaweed-based animal feed market to over USD6bn by 2050, and seaweed's strong sustainability credentials relative to most other products, we expect larger animal feed companies to seek to expand their presence in this market. Some of the largest producers of feed additives include Cargill, Royal DSM, Alltech, DuPont and BASF. Some of the largest companies operating in the global animal feed market are listed in Figure 57.

Figure 56: Market potential for seaweed as an animal feed additive
Assuming that seaweed additives comprise 3-5% of animal feed



Source: IFIF, World Bank, FAO, Standard Chartered Research

Figure 57: Largest animal feed manufacturers globally

Company	Country	Production (Mt)
CP Group	Thailand	28.18
New Hope Group	China	28.00
Haid Group	China	19.63
Cargill	United States	19.60
Land O'Lakes	United States	13.50
Muyuan Foodstuff	China	13.11
JBS	Brazil	11.00
Twins Group	China	11.00
BRF	Brazil	10.07
ForFarmers	Netherlands	10.00

Source: Feedstrategy, Standard Chartered Research

Company profile:

Sea6 Energy

Overview

Sea6 Energy is a seaweed company headquartered in Bangalore, India. It has operations in Indonesia and sales in over 20 countries. Financial investors include BASF Venture Capital, Silverstrand and Tata Capital Innovations Fund. Sea6 Energy is exposed to a range of seaweed end markets.

Relevance to the seaweed industry

The company was founded in 2010 and has been selling seaweed-based biostimulants since 2015. It is currently developing carrageenan-based food ingredients and bioplastics, which it expects to start selling in the next six months. Sea6 Energy's product range includes biostimulants, organic fertilisers, animal feed (poultry- and aqua-focused), food ingredients and biomaterials.

In addition to developing seaweed products, Sea6 Energy has developed tools to increase the efficiency and scale of seaweed farming. Its SeaCombine™ technology platform automates the seeding and harvesting process. To help scale up the seaweed industry, Sea6 Energy is setting up a 1km2 (100-hectare) seaweed farm in Indonesia, which it intends to manage with the help of the SeaCombine™ platform. This should also generate environmental data that will help to optimise the operation of large-scale seaweed farms.

Sea6 Energy believes that the optimisation of seaweed production processes will have a significant impact on production, and it expects the introduction of industrialised production technologies to reduce the production cost of red seaweed by 90% from current levels.

Sea6 Energy's view on the seaweed market

The company believes that the seaweed market can more than double over the next five years. However, to unlock that growth, key hurdles need to be addressed. These include the streamlining of regulation, especially in relation to the licensing of ocean areas used to grow seaweed and the approval of specific seaweed species. This would help to address the lack of biomass for newer applications, which is currently the key factor limiting industry growth, according to Sea6 Energy.

Although Sea6 Energy is positive on the outlook for the seaweed industry overall, it notes that some areas face greater challenges than others. For example, bioplastics are currently not cost-competitive, and the scalability of methane reduction products remains uncertain, according to the company. It believes that large-scale cultivation and optimisation of seaweed production costs can improve the scalability and economic viability of bioplastics.

Seaweed can help improve coastal economies

In addition to the environmental and health-related benefits discussed above, the seaweed sector has strong potential to address poverty and inequality, especially in coastal economies in the developing world.

Almost 40% of the global population lives on or near the coast, according to the UN. The world's coastal population contributes almost USD1.5tn to the global economy, and the UN projects that this could double to USD3tn by 2030. Currently, over 6mn smallholder farmers and their families in 48 countries depend directly on seaweed production. Seaweed farming in developing countries is often a 'whole family' operation, with both women and men active in production, according to UN studies. In addition to supporting local economies, a sustainable growth strategy for seaweed production could therefore help to address gender inequality by supporting women's role in local economies.

Increasing annual global seaweed production volumes to 500Mt dry weight by 2050 would potentially create 50mn new seaweed farming jobs and 100mn new jobs in total (assuming a multiplier effect of 2:1), according to a World Bank report.

Increased seaweed production has indirect as well as direct economic benefits for coastal communities in emerging economies. For example, seaweed aquaculture can protect coastal systems and improve local food security. Canopies of farmed seaweed dampen wave energy, providing protection for coastal structures and reducing coastal erosion. Norwegian kelp has been reported to reduce wave heights by up to 60% (Mork, 1996). Furthermore, dense seaweeds may protect oceans from acidification given their absorption of CO2 during photosynthesis. They therefore help to restore or protect local biodiversity, which in turn supports local food production and fishing-exposed economies.

Seaweed farming has significant potential to expand to new geographies, broadening its positive impact on poverty and inequality. Of the 132 countries that have marine ecosystems suitable for seaweed production, only 37-44 are currently actively producing seaweed (Froehlich et al, 2019). While Asian countries currently account for almost the entire seaweed market, we expect Africa in particular to benefit from further development of the industry. Eight African countries – Egypt, Nigeria, Senegal, Benin, Tanzania, Somalia, Côte d'Ivoire and Mozambique – will be among the 20 countries with the largest coastal populations by 2060, according to estimates from Neumann et al (2015); their coastal populations are projected to increase by more than 150mn between 2000 and 2060. More recent estimates from Reimann et al (2023) project a 2.5 to 5-fold increase in the size of Africa's coastal population to 265mn by 2100 (compared to Asia's projected coastal population of 784mn at that time)

Some African countries are already engaged in seaweed production, albeit on a relatively small scale; they include South Africa, Namibia, Mozambique, Madagascar, Tanzania, Kenya, Nigeria, Ghana, Senegal and Morocco. In our view, a well-organised and expanded seaweed industry in these coastal communities is crucial to accommodating expected population growth in a sustainable way.

Company profile:

Coast 4C

Overview

Coast 4C is a social enterprise that was founded in 2020 and is based in Australia. Its aim is to produce high-quality and responsibly farmed seaweed in quantity, in order to meet growing seaweed demand from responsible global brands and deliver positive impact across the '4Cs' (communities, commerce, conservation and climate).

Relevance to the seaweed industry

The current seaweed industry relies heavily on smallholder farmers, and the well-being of coastal communities depends on the production and sale of seaweed by these farmers. A key challenge for the current seaweed industry is the inability of independent seaweed farmers to modernise their practices and adapt to the impacts of climate change. As a result, they suffer from declining yields and declining quality, ultimately driving down income for their families and local communities.

Coast 4C aims to integrate the supply of seaweed, and is currently doing this through a network of suppliers based in the Philippines. Coast 4C focuses on eucheumatoids, a seaweed species that produces carrageenan, which is used in human food, pet food, cosmetics, household products and pharmaceuticals. Coast 4C plans to replicate its approach in Indonesia over the next few years. In addition to its focus on seaweed farmers, Coast 4C recognises that some 22mn smallholder fishers globally struggle to make a living due to declining catches. By offering a fully integrated approach to seaweed production, Coast 4C believes that it supports the livelihoods of fishers as well as seaweed farmers.

Given its integrated supply chain, Coast 4C is able to generate higher seaweed prices for its farmers, linked to meeting quality, social and environmental criteria. Coast 4C helps farmers achieve these criteria by providing them with access to new production methods and seaweed strains that enhance productivity. Coast 4C aggregates output from individual coastal communities to end markets, increasing farmers' pricing power. Coast 4C integrates seaweed farming with larger marine protected areas, with the aim of creating a safe and healthy space for seaweed production while restoring marine biodiversity.

In addition to its seaweed and fishery solutions, Coast 4C focuses on removing old fishing nets from the oceans. Coast 4C notes that an estimated 46% of plastic items documented in the 'Great Pacific Garbage Patch' are from abandoned, lost or discarded fishing nets. Removing these nets from the ocean is key to eliminating plastic waste. This is particularly relevant for smallholder fishers, who tend to replace their nets every six weeks, according to Coast 4C. Discarded fishing nets not only degrade ocean biodiversity of oceans, but they also create additional replacement costs for seaweed farmers, creating an impediment to their livelihoods.

Recycling fishing nets made from so-called Nylon 6 has a high value and can be integrated into products with a negative carbon footprint. Through special-purpose cooperatives, Coast 4C buys nets from coastal communities, providing them with additional income, and sells these nets into the circular economy.

Seaweed investing to yield value and jobs

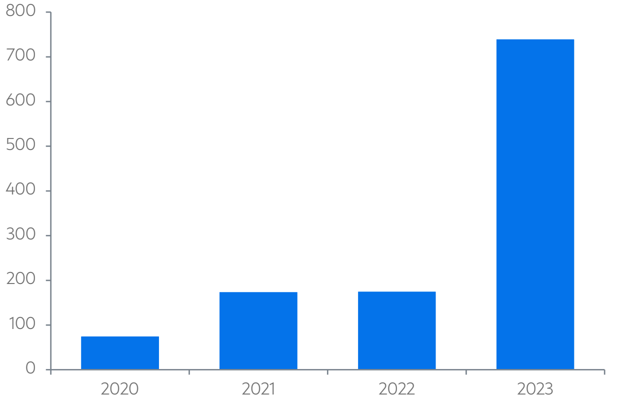
A key question is how quickly and effectively the seaweed industry can scale up production capacity to realise its strong structural growth potential. Access to financing is almost always a hurdle to expanding production capacity, according to our conversations with seaweed companies and NGOs. We believe that investment prospects for the seaweed industry are compelling, and that the acceleration of investment in the industry in recent years suggests that financing might start to become more available.

Investment in seaweed appears to be accelerating

Globally, investment in the seaweed industry more than doubled to USD176mn in 2022 from USD76mn in 2020, according to data from Phyconomy, which tracks the industry; during the first seven months of 2023, investments surged to USD740mn. This data only represents disclosed investments.

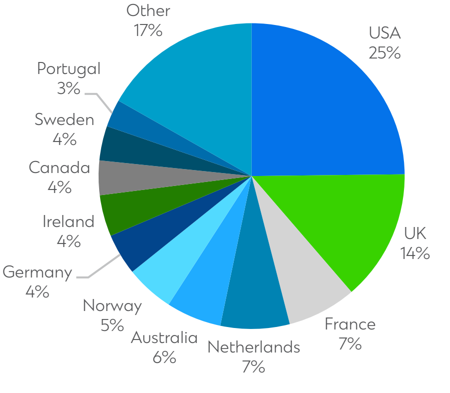
The 73 investments disclosed since 2020 show a strong bias towards brown and red seaweed, which together make up c.90% of investments by value. From a geographical perspective, almost 75% of the investments were made in companies with head offices in Europe or the US, while only 9% went to companies based in Asia or other EM regions.

Figure 58: Disclosed investments in seaweed companies (USDmn)



Source: Phyconomy, Standard Chartered Research

Figure 59: Investment by corporate head office location



Source: Phyconomy, Standard Chartered Research

Direct investment is starting to accelerate

We see early signs that investors are starting to recognise the attractiveness of seaweed as an investment opportunity.

- In March 2023, DWS Group invested more than USD600mn in South Korean seaweed company Botamedi as part of a Series B investment round, according to Dealroom data. This is the biggest investment (by some margin) that we have identified by a single entity in a seaweed company.
- In June 2023, Ocean Harvest Technology listed on the UK AIM market, making it the first publicly traded pure-play seaweed company. Although the shares have performed poorly since listing, we see this as another indication that seaweed may become a broader investable theme

- Historically, larger non-financial corporates have been the main buyers of seaweed companies. Examples include food companies such as Cargill or ADM, and consumer staple companies such as P&G, Unilever or Nestlé. More recently, a growing number of larger companies have started to take direct stakes in seaweed companies. Examples include Estée Lauder, H&M, ASICS, BASF and Tyson Foods (Figure 60).

Figure 60: Corporate investments in seaweed companies – Examples

Seaweed company	Investor	Date
Botamedi	DWS	Mar-23
Mari Oceans	Swiss Re	Oct-22
Algo Paint	Amundi, EDF	Oct-22
Sea6 Energy	BASF, Tata	Aug-22
Keel Labs (prev. Algiknit)	H&M	Jun-22
Symbrosia	Danone	Jun-22
Haeckels	Estée Lauder	Jun-22
The Seaweed Company	Colruyt	Mar-22
Pyratex	ASICS	Jan-22
New Wave Foods	Tyson Foods	Jan-21
Arctic Seaweed	Orkla	Sep-20

Source: Phyconomy, Standard Chartered Research

Assessing the profitability of seaweed farming – Our model

A lack of external funding is a key challenge to unlocking the significant growth we expect in the seaweed industry. All market participants that we have spoken with indicate that this is partly because external financiers view seaweed production volumes as too low, creating a classic 'chicken-and-egg' challenge for the industry. The positive outlook for seaweed-exposed end markets may not be sufficient to attract the required capital to the sector. With much of the current seaweed market driven by smallholder farmers, the profitability of large-scale farming remains unclear to investors. A greater understanding of the profitability of seaweed investing may therefore be needed to unlock increased funding. To provide insight on this, we have built a financial model for a hypothetical seaweed farm.

A financial model for seaweed farming

To assess value creation from seaweed farming, we have modelled the potential revenue profile of a 10-hectare seaweed farm, the capital expenditure needed to set it up, and the operating expenses of running it. For our assumptions we have relied on several studies in recent years that have aimed to assess the cost of seaweed farming .[1]

A key consideration factored into our model is that production characteristics differ between seaweed farms in tropical or warmer conditions and those located in temperate or boreal areas. For example, farms in colder areas typically have only one growth cycle per year, while those in warmer areas may have six to eight (or more).

We also find that the seaweed farms in colder climates tend to have higher production yields in terms of kilogrammes of seaweed per metre of growth line – as high as 20kg/m, typical levels of up to 5kg in warmer areas.

[1] Coleman et al (2022) quantified baseline costs for kelp-related carbon dioxide removal farming approaches. Kite-Powell et al (2022) estimated production costs for large-scale seaweed farms. The Crown Estate Scotland published an economic feasibility study on seaweed in 2021. Other studies assessing the operating costs of seaweed farming are highlighted in Figure 73 in the Seaweed is not without its challenges section of this report.

To account for these discrepancies, we have built two models, one for a brown seaweed (kelp) producer in colder conditions and one for a red seaweed producer in a warmer area.

When setting up our financial models, we assumed that the farm located in colder conditions is in a more economically developed region. As a result, labour costs will be higher but access to technology will be easier, allowing faster adoption of production efficiency measures. In line with this, our colder farm features grow lines 200m long with a 1m distance between the lines. The farm located in a warmer climate also has 200m grow lines, but they are separated at a 3m distance.

We recognise that our models are based on a wide range of assumptions, each with a degree of uncertainty; however, we hope they provide a useful starting point for investors when engaging with seaweed-related stakeholders. While our models assume a 10-hectare farm size, our approach is designed to be modular in nature, suggesting that larger farms should be at least as profitable thanks to economies of scale.

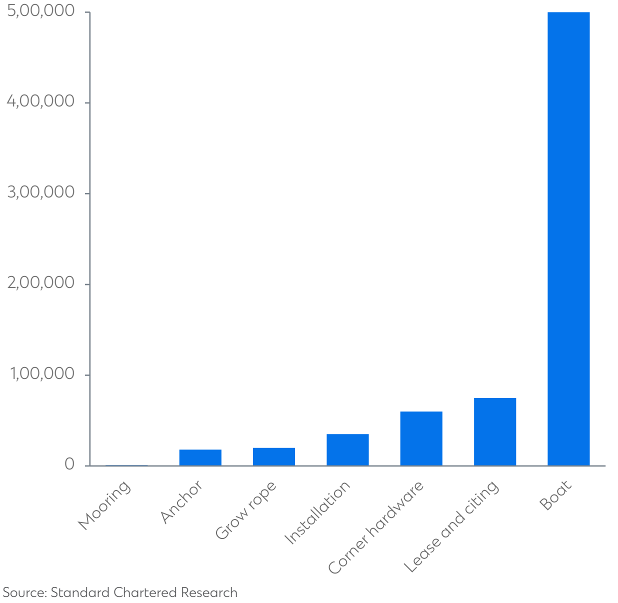
Investment costs associated with seaweed farming

Key investment costs associated with setting up a seaweed farm include anchors and mooring expenses, grow line-related costs, buoy-related expenses, installation costs, leasing expenses, siting costs and the purchase of a boat. Based on separate assumptions for all of these items, we assume initial capital expenditures of USD0.7mn to set up our kelp/brown seaweed farm and c.USD0.5mn for our red seaweed farm. It is worth pointing out that more than half of these amounts relate to the boat purchase (Figure 61).

We assume that all of the assets except the grow lines have a lifespan of 15-20 years. We assume that the grow lines will be replaced after 15 harvests. This means that our brown seaweed/kelp farm will have to invest in new lines every 15 years (as it has one growth cycle per year).

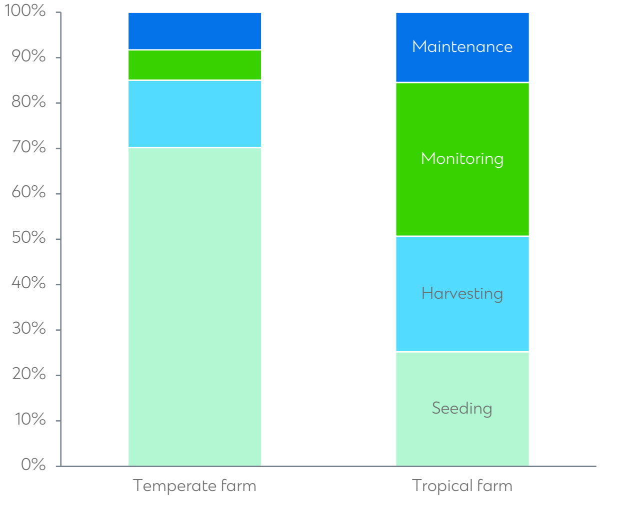
Our red seaweed farm will have to invest in new lines every 2.5 years given its more frequent growth cycles. Based on our lifespan estimates, we calculate annual depreciation expenses of approximately USD32,000 for our kelp farm and USD25,000 for our red seaweed farm. A more detailed overview of our capital expenditure estimates for the first 10 years of the farm's operations is provided in the **appendix.**

Figure 61: Capital expenditure of a red seaweed farm
USD



Source: Standard Chartered Research

Figure 62: Breakdown of cost of goods sold by group
% share in year 1 of operation



Source: Standard Chartered Research

Operating expenses associated with our farms

Our modelling of both farms' direct operating expenses, or cost of goods sold, covers four broad cost areas: (1) seeding, (2) harvesting, (3) monitoring and (4) farm maintenance. Our seeding cost estimates include assumptions for per-metre nursery and seeding costs, wage costs associated with the seeding process, and fuel costs associated with boat use. We note that nursery and seeding costs are mainly incurred by our kelp farm, since brown seaweed species (such as kelp and nori) require the onshore phase of facilitating the microscopic stage of their lifecycle; in contrast, red seaweed can be grown by cutting branches from larger existing plants and attaching them to the grow lines. We assume that monitoring is done four times per growing cycle. For farm maintenance expenses, we assume that the brown seaweed/kelp farm requires fewer staff given its higher efficiency, but that its staff cost more (USD15 per hour, versus USD5 per hour for the red seaweed farm).

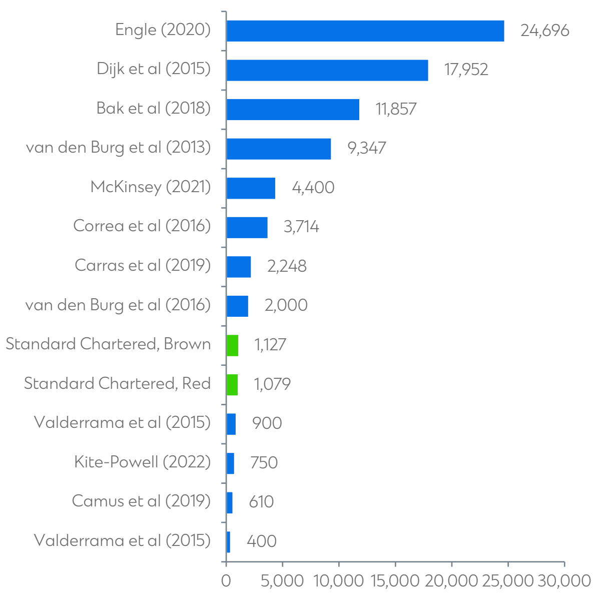
Based on our assumptions, we estimate that 70% of the kelp farm's cost of goods sold relate to the seeding process (Figure 62). We have assumed nursery and seeding costs of USD0.75 per metre (within the USD0.12-1.38 range estimated in a 2021 study by Coleman et al), but we recognise that these costs may fall as the industry matures.

Based on our assumptions for the two farms' various operating expenses, we estimate that their total operating expenses per tonne of dry seaweed are similar, at USD1,079 for the red seaweed farm and USD1,127 for the brown seaweed/kelp farm. These estimates are in line with other analysis, as indicated in Figure 63.

The seaweed farmers we spoke to believe that operating costs per tonne of seaweed can be reduced significantly. Modelling from Kite-Powell et al (2022) suggests that operating costs per tonne of dry weight could fall by 80% when farm sizes are increased from 10ha to 10,000ha. One of the seaweed farming companies that we spoke to said that it expects a 90% reduction in its operating cost per tonne of seaweed as it automates and optimises production.

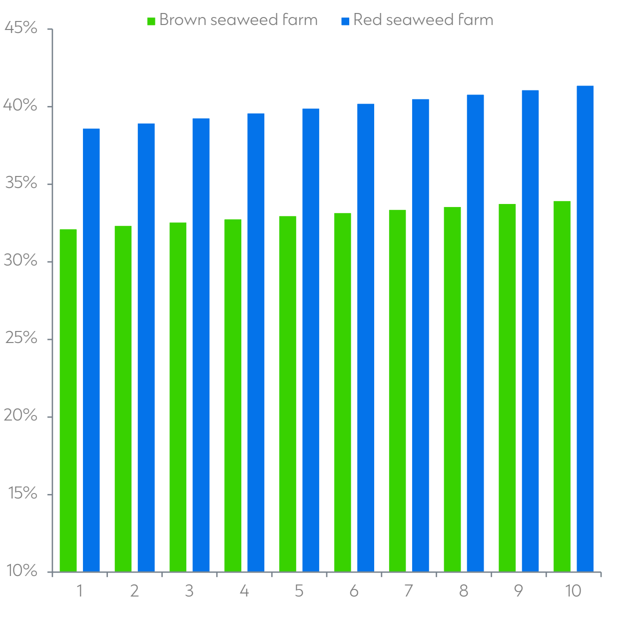
Our base-case estimates leave both of our farms with healthy EBITDA margins (Figure 64). The kelp/brown seaweed farm's narrower EBITDA margin is mainly due to its higher nursery and seeding costs. Reducing these costs would narrow the margin differential with the red seaweed farm.

Figure 63: Operating cost comparison
USD per tonne of dry weight



Source: Kite-Powell et al (2022), Coleman et al (2021), Standard Chartered Research

Figure 64: EBITDA margins of our model farms
%



Source: Standard Chartered Research

Revenue potential for seaweed farming

To estimate the revenue potential for our farms, we make assumptions on the number of growing cycles per year, the yield that can be achieved (measured in kg of fresh seaweed per metre of growing line), and the price for a tonne of fresh seaweed.

Based on key operational statistics for existing seaweed farms and our interactions with seaweed farmers, we assume that our brown seaweed/kelp farm has one growing cycle per year and achieves a yield of 15kg of fresh (wet) seaweed per metre. For our red seaweed farm, we assume six annual growth cycles and a yield of 4kg/m.

Our base-case scenario is that both farms can receive a price of USD1,500 per tonne of dry seaweed (while farms can also sell wet seaweed, we do not incorporate this into our modelling). Price estimates are complicated by wide variations between seaweed species, but our research suggests that dry seaweed sells for up to USD2,000 per tonne, and this was confirmed in our conversations with farmers.

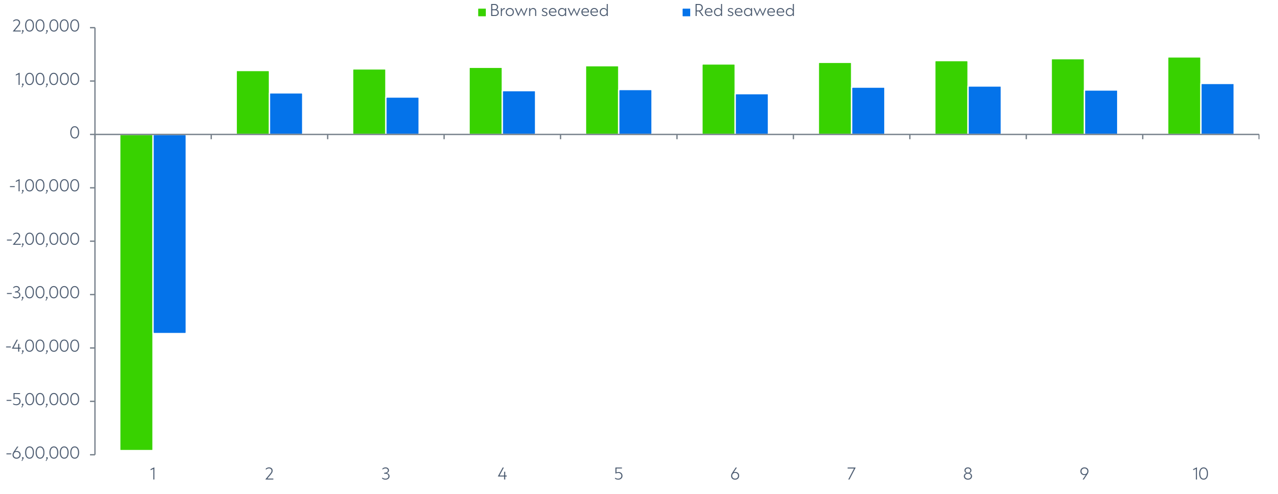
Based on our assumptions for yield, number of growing cycles and prices, we estimate that our 10ha brown seaweed/kelp farm could generate turnover of USD450,000, while our red seaweed farm could generate USD240,000. Companies typically increase revenues either by increasing production or raising prices. In the case of both our farms, increasing revenues seems difficult in the absence of efficiency-enhancing techniques including automation. The costs associated with this may be challenging for seaweed farmers at this stage, especially in developing regions. Our model assumes only a 1% annual improvement in yield. This does suggest future upside potential if affordable automation technologies become more widely available.

Potential cash-flow generation

To calculate the value of our seaweed enterprise, we estimate the free cash flow generated over a 30-year period. This allows us to capture at least two investment cycles, considering that the lifespan of some of the more expensive equipment is 20 years or more.

We calculate free cash flow by deducting annual capital expenditure from net operating profit after tax. Our estimates indicate that both farms should turn free cash flow-positive in year 2 (Figure 65). Annual free cash flow should be above USD100,000 for the brown seaweed/kelp farm, while the red seaweed farm is not estimated to achieve these levels during the first 10 years of operation. (See the appendix for a more detailed breakdown of our profit and loss, cash flow and balance sheet-related estimates.)

Figure 65: Free cash flow estimates for our brown seaweed (kelp) and red seaweed farms
(USD, by year of operation)



Source: Standard Chartered Research

Establishing the value of a seaweed farm

To assess the attractiveness of an investment in seaweed farming, we have calculated the internal rate of return for our hypothetical seaweed farms, as well as their potential equity value.

We assume that both farms have a leverage ratio of 50% at the start, although this can be adjusted depending on desired profitability and risk preferences. As farms get bigger, this share may have to rise along with the increase in required investments.

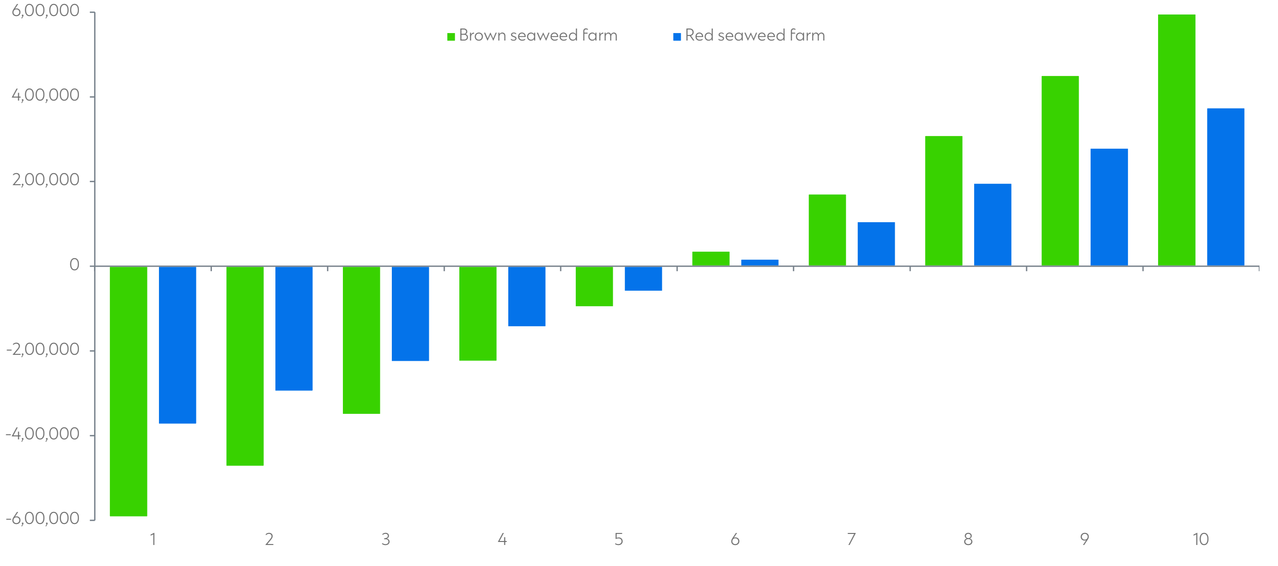
To establish the equity value, we have built a discounted cash flow (DCF) model covering 30 years of operation. We use a weighted average cost of capital that incorporates a cost of debt 200bps above the 10Y UST yield. For the implied equity risk premium, we use 4% (the most recent estimate from Aswath Damodaran of the NYU Stern School of Business). Based on our discounted stream of free cash flow and terminal value, we calculate that our 10ha brown seaweed/kelp farm has an enterprise value of c.USD2.9mn and an equity value of c.USD2.7mn. Using the same approach for our red seaweed farm gives us an enterprise value of USD1.1mn and an equity value of USD1.0mn.

The key reason why the brown seaweed farm is more valuable than the red seaweed farm is that its higher revenue base supports higher absolute free cash flow, despite its somewhat lower margins. We note that price development will be a crucial factor in determining value creation going forward. However, considering the growing level of interest in seaweed-related products and their sustainable characteristics, we would not be surprised if demand outstrips supply, even if investments in additional production capacity pick up. All else being equal, this should support higher selling prices for both red and brown seaweed, in our view.

The IRR of a seaweed farm

In addition to the net present value calculation for our seaweed farm, we have calculated the internal rate of return (IRR). When solving for the discount rate that equates our estimated stream of free cash flow to the initial investment needed, we find that the base-case IRR of both of our seaweed farms is very similar – 22.0% for the brown seaweed/kelp farm and 21.9% for the red seaweed farm.

Figure 66: Cumulative discounted free cash flow generation by year
USD



Source: Standard Chartered Research

To understand the sensitivity of seaweed farming profitability, we ran various scenarios. For the red seaweed farm, we reviewed the potential impact of different yields and numbers of annual harvests. Our calculations suggest that the IRR for a red seaweed farm can increase to almost 40% if it can achieve eight growth cycles per year with an average yield of 4kg/m (Figure 67). While we have assumed six cycles in our base case, eight cycles are not uncommon. A more problematic scenario would be a combination of only growth cycles with a yield of 3kg/m, which would generate a negative IRR on our calculations.

We also calculated the breakeven point for both farms' IRRs in relation to the price of dry seaweed. Our calculations suggest that at current operational efficiency levels, a 10-hectare brown seaweed/kelp farm should continue to generate a positive IRR as long as the price of dry seaweed is above USD1,100 per tonne (Figure 68). In the case of the red seaweed farm, we find that it can withstand a slightly lower price of USD1,050 before the IRR turns negative. The key reason for the difference is the smaller upfront investment costs we have assumed for the red seaweed farm.

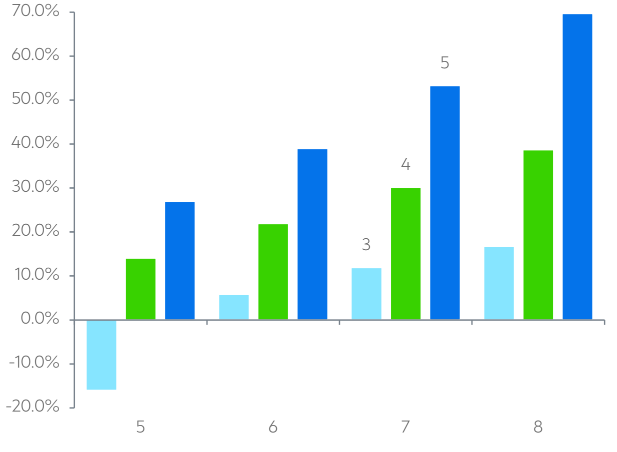
The seaweed market could be worth USD313bn

Using our financial model for a hypothetical 10-hectare seaweed farm, we can translate the potential of seaweed-related end markets (discussed in the **Seaweed as sustainable disruptor section**) into required investment needs and their associated or implied value proposition. The purpose of this calculation is to assess how significant an opportunity seaweed farming may be for financial investors, and how these investments could potentially be structured.

To meet demand from the five end markets highlighted in this report – food and alternatives, biostimulants, bioplastics, methane reduction and animal feed – we estimate seaweed production growth of c.13% per year until 2030, followed by 10% annual growth for the 10 years thereafter (Figure 69). All of this growth would come from new farms rather than existing production facilities, which already serve existing demand.

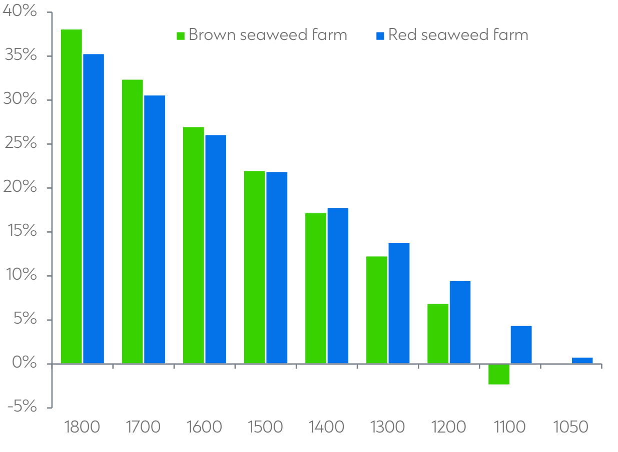
To calculate the investment needed to achieve these growth rates, we consider that some of these end markets (e.g., animal feed, bioplastics and biostimulants) rely largely on brown seaweed, while others (e.g., methane reduction products) require red seaweed species. We incorporate the differing investment and value propositions of these two types of seaweed farming into our calculations of the overall seaweed-related market opportunity.

Figure 67: IRR scenarios for red seaweed farm
IRR (y-axis), number of harvests per year (x-axis); bars show different yields (kg/m)



Source: Standard Chartered Research

Figure 68: IRR as a function of dry seaweed price
Seaweed price in USD/tonne of dry weight



Source: Standard Chartered Research

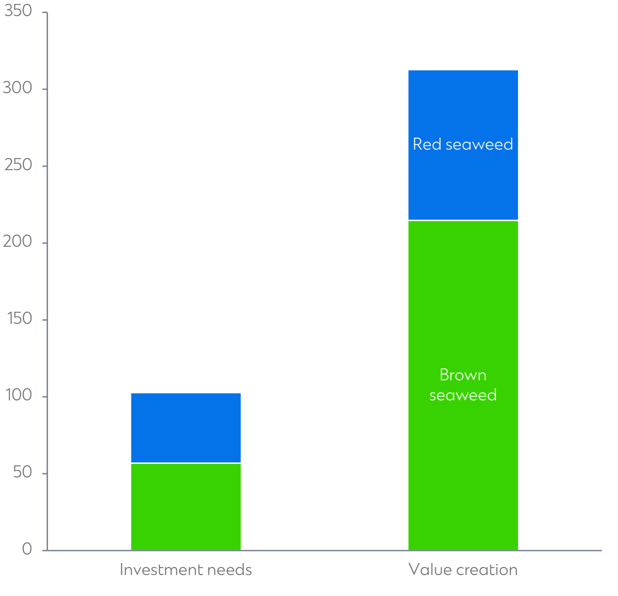
We calculate that c.USD29bn of investments would be needed until 2030, and another USD73bn between 2030 and 2040, to realise seaweed's production potential (Figure 70). This comes out to USD103bn of investments, which we assume are equally split between debt and equity. While this may appear challenging, we estimate c.USD313bn of equity value generation from newly established seaweed production sites. Based on a 50/50 debt-equity split, this implies that equity investors' c.USD51bn of total investments would increase to a value of c.USD313bn between now and 2040 – implying an attractive annual average growth rate of c.11%. We find that seaweed is also a compelling investment proposition for bond investors with a sustainable mandate, given the structural nature of growth in the market, its relevance to a broad set of sustainable targets, and our assumed debt yield of c.7% going forward.

Figure 69: Seaweed production potential in key end markets
Mt, under our base-case scenario

	2022	2030	Change	2040	Change
Food and alternatives	28	62	34	133	71
Biostimulants	5	13	8	40	27
Bioplastics	0	4	4	27	23
Methane reduction	0	10	10	29	20
Animal feed	0	2	2	6	4
Total	33	88	55	229	141
CAGR		13%		10%	

Source: Standard Chartered Research

Figure 70: Seaweed investments and value creation
USD bn



Source: Standard Chartered Research

Seaweed cultivation may generate 200mn new jobs

Our estimates of the potential value of these emerging seaweed markets only capture company-related aspects. They do not incorporate the indirect economic multiplier effects that are also likely to be achieved – namely, the potential for large-scale job creation as new seaweed farms are established.

Estimates of potential job creation from seaweed farming vary. The World Bank estimated in a 2015 publication that every 10 tonnes of dry seaweed would yield one job. In 2020, the trade group Seaweed for Europe estimated a much greater employment impact, with the entire seaweed supply chain (from hatchery to distribution) generating 27 full time jobs for every tonne of dry weight, using a 10:1 wet-to-dry ratio.

Using the more conservative World Bank estimates, we estimate that increasing seaweed production to our projected 2040 level would create more than 200mn new jobs. This would provide strong impetus for a number of the UN SDGs, considering that most seaweed farming is likely to remain based in developing economies. Our job growth estimates could prove overly optimistic, however, if large-scale automation of seaweed farming becomes affordable and is needed to raise production to our assumed levels.

Guaranteed seaweed investment vehicles are needed

Despite seaweed's strong value proposition, securing access to funding has been a key challenge for the industry. This needs to be addressed, in our view, if the market's full potential is to be achieved.

Access to financial services (including loans) has been a challenge for smallholder seaweed farmers in developing countries. Reasons for this include a lack of collateral, high interest rates, and lenders' lack of knowledge about the seaweed business (and vice versa). Improvement of regulatory and licensing systems would help to address some of these hurdles.

However, even a strong improvement in the regulatory framework would not solve the issue that investment projects need to be large enough to attract institutional investors. Given the small scale of most current seaweed farmers, this may be a challenge. This suggests that enabling the development of market-based funding mechanisms for the seaweed industry (such as blue bonds and green finance) may require a different approach. We believe that large-scale funding of seaweed investments would be easier if:

- **Seaweed investment needs were pooled.** This way, the cumulative investment opportunity for investors would be large enough to become interesting to them. A pooled investment approach would also reduce investment risk by spreading exposure across many individual investment projects.
- **External agencies provided guarantees.** To reduce the risk profile of seaweed investing, and also lower the interest cost for borrowing seaweed farmers, these investment vehicles could carry a guarantee from entities such as the World Bank, the EU or regional development banks. Considering the importance of seaweed farming in achieving long-term sustainability targets, we believe that such guarantees would be worth it.
- **Regional funds are established.** To enable the development of new seaweed markets, we believe that it may be helpful to establish regional seaweed funds. For example, an Africa-focused guaranteed fund could help to develop the region's seaweed industry while also improving coastal livelihoods.

We believe that guaranteed seaweed investment vehicles would be able to attract sufficient capital to achieve the seaweed industry's potential, improve the outlook for smallholder seaweed farming, and support the development of large-scale industrialised seaweed farming.

Seaweed is not without its challenges

While the outlook for seaweed as a sustainability theme is positive, several key issues will need to be addressed if seaweed's full potential is to be unlocked, in our view.

The degree of carbon sequestration remains unclear

While seaweed has largely been produced as a food ingredient until now, its role in climate change mitigation and adaptation is receiving growing interest. Half of global CO_2 that is converted into organic compounds occurs in the oceans (Nelleman et al, 2010), and wild seaweed covers an area 10-40x larger than seagrasses, tidal marshes and mangroves (Duarte, 2017). However, the extent to which seaweed is sequestering carbon – and its maximum sequestration potential, especially in relation to climate mitigation – is unknown at this point. According to one estimate, wild seaweed captures 173 terragrammes (Tg) of carbon per year (Kraus-Jensen and Duarte, 2016); wild seaweed covers an area of 7.2mn km^2, comparable to the Amazon rainforest (Duarte et al 2022).

Seaweed aquaculture is believed to store much less carbon than wild seaweed; the highest estimate is just 0.4% of the amount stored by wild seaweed. The carbon storage potential of seaweed aquaculture appears strong, based on estimates from Duarte, who calculated in 2017 that it could reach 1,500 tonnes of CO_2 per km^2 of farming per year.

Given the size of the open ocean, seaweed can in theory become a large contributor to global carbon sequestration if efficient offshore cultivation methods are developed. One study calculated that if 9% of the world's ocean area were used for seaweed aquaculture, emissions could be reduced to pre-industrial levels within a few decades (N'Yeurt et al, 2012).

Estimates of seaweed-related carbon sequestration vary widely. A recent study (Pessarrodona et al, 2023) estimated that the natural carbon sequestration of all macroalgal habitats ranges from 61-268 Tg of carbon per year. Seaweed can contribute to climate change mitigation via several channels:

- Protecting and restoring wild seaweed forests, with potential climate change mitigation benefits
- Expanding sustainable nearshore seaweed aquaculture with potential climate change mitigation co-benefits
- Offsetting industrial CO_2 emissions using seaweed products for emissions abatement
- Sinking seaweed into the deep sea to sequester CO_2

Oceans 2050 to settle carbon questions

Recognising the need for clarity on carbon accounting in relation to seaweed, the Oceans 2050 organisation (which includes several leading marine scientists, including Professor Carlos Duarte) conducted a 15-month global study to quantify carbon sequestration by seaweed. The study was based on 23 seaweed farms in Asia, Europe, North and South America, and Africa. The results showed that carbon sequestration averaged 1.4 tonnes per hectare per year, albeit with a wide range of 0-8 tonnes. The Oceans 2050 team is now developing a voluntary carbon offset methodology for seaweed; if approved, it should help farmers earn additional income while expanding the range of carbon-offsetting tools available to companies that buy carbon credits as part of their emissions offsetting strategy. Despite uncertainty on the the magnitude of carbon sequestration by seaweed, there is an increasing focus on protecting, managing, restoring and expanding seaweed forests to mitigate the impact of climate change. For seaweed strategies to credibly claim that they contribute to climate change mitigation, they must adhere to a few criteria:

- **Additionality:** Whether the seaweed forests modify emissions or remove greenhouse gas emissions that otherwise would not have happened. A relatively wide range of potential projects could be established that meet the additionality requirement. These projects either aim to avoid a decrease in carbon sequestration or actively increase the amount of carbon that is stored. We highlight some examples in Figure 71.
- **Permanence:** The removal of greenhouse gas emissions has to be permanent; in practice, this typically means that these emissions are stored for well over 25 years, although a much longer (100-year) period is increasingly being used.
- **Governability:** The seaweed projects must be established in jurisdictional areas that allow for proper policy, measurement and management oversight.

Figure 71: Projects that have the potential to improve the carbon flux of seaweed forests

Type of project	Examples
Avoid decrease in carbon sequestration capacity	
Directed at the carbon source	
• **Avoidance of direct habitat loss**	Manage seaweed harvest, decrease reef mining, land reclamation and coastal development
• **Avoidance of indirect habitat loss from overgrazing**	Grazer management (e.g., protection of urchin predators such as sea otters and sustainable management of coastal fish stocks)
• **Avoidance of indirect habitat loss from poor water quality**	Catchment area management to reduce nutrient inputs, sedimentation
Directed at the carbon sink	
• **Avoidance of marine sediment disturbance**	Management of coastal vegetated sediments, reduce trawling and dredging activities
Increase carbon sequestration capacity	
Directed at the carbon source	
• **Management of wild habitats to increase sequestration**	Catchment area management to increase seaweed productivity
• **Re-establishment of previously lost habitat**	Seaweed forest restoration
• **Creation of new habitat**	Coastal afforestation, expansion of coastal aquaculture

Source: Pessarrodona et al, 2023, Standard Chartered Research

Seaweed farming may create environmental risks

The substantial increase in seaweed production volumes that we envision creates several potential environmental challenges. We highlight some of these below.

- **Absorption of light:** Seaweed growth requires light. The development of large-scale seaweed farms consisting of so-called seaweed forests could increase shade for organisms living below the seaweed (known as benthic shading). This could negatively impact the growth of non-seaweed plants further below the surface, reducing their carbon storage capacity – thereby reducing the net carbon storage benefit of growing seaweed. Biodiversity might also be impacted (especially by large-scale farms) if, for example, phytoplankton compete with the seaweed for light.
- **Absorption of nutrients:** The introduction of seaweed could lead to a sharp decline in the concentration of some nutrients, negatively affecting coastal ecosystems and related services. Furthermore, large-scale seaweed systems may impact water flow, which could affect the capacity to carry nutrients and reduce nutrient concentration. A potential solution would be to locate seaweed farms in areas with artificially high nitrogen resources, including salmon farms.
- **Alteration of water flow:** Seaweed farms alter water flow as they absorb tidal energy. A 2011 study by Grant and Bacher showed that water flow was reduced by 54% within a seaweed cultivation area, and by 20% along the open channels within the farm. While reduced water currents may protect coastal systems and thereby protect life on land, reduce water flow within seaweed farms may affect the water's nutrient-carrying capacity, negatively affecting habitats below the seaweed structure.
- **Release of dissolved and particulate matter:** Large seaweed farms are likely to release additional organic matter through losses from wave action, decomposition or harvesting. Lost plant tissue may be deposited on the seabed, affecting local benthic habitats. Importantly, this lost solid material does not necessarily stay near the seaweed farm and may also impact biodiversity further away.

Figure 72 highlights some of the other key environmental challenges associated with large-scale seaweed farming.

Figure 72: Key potential environmental risks associated with large-scale seaweed farm development

Drivers of environmental change	Potential impact	Measures to mitigate impact
Release of reproductive materials	• Altered genetic composition of local species resulting in loss of natural fitness or community composition	• Use of locally sourced reproductive materials • Production of seeding materials that maintain genetic integrity
Facilitation of disease, parasites and non-native species	• Potential widespread consequences for marine communities and ecosystem functioning	• Biosecurity measures to manage introduction risk • Combine monitoring and research to inform management systems
Absorption of kinetic energy	• Large scale-changes in local hydrodynamics, with many potential receptors affected	• Detailed siting analysis to minimise risk • Siting analysis with a focus on mitigating risks
Addition of cultivation systems	• Elevated megafauna mortality due to entanglement with cultivation systems	• Develop cultivation systems with minimal entanglement risk • Siting analysis to avoid negative impact for local communities
Nutrient absorption	• Local nitrogen absorption resulting in compositional changes in phytoplankton community	• Cultivation projects in suitable water bodies with high anthropogenic sources of nitrogen • Adjustment of stocking density within cultivation areas
Artificial habitat creation	• Potential widespread consequences for marine communities and ecosystem functioning	• Siting analysis to incorporate negative impacts and minimise risks
Absorption of light	• Benthic and/or pelagic shading resulting in community compositional changes	• Develop sites that avoid protected communities • Adjustment of stocking density within cultivation area

Source: Campbell et al (2019), Standard Chartered Research

Seaweed carbon credits face several challenges

Given the carbon storage potential offered by seaweed, growing corporate interest in seaweed-based carbon credits is not surprising. We believe that the voluntary carbon market can play a significant role in achieving long-term emissions targets, and that seaweed can play a role if its carbon sequestration capacity can be clarified and a strong seaweed-carbon credit market can be established.

Several organisations and academics are working on developing a seaweed carbon credit system. Ross et al (2023) have identified five potential methodologies, of which they consider two more immediately actionable: (1) carbon deposited in sediment below seaweed farms, and (2) emissions abatement credits from seaweed products.

However, several challenges will need to be addressed before voluntary carbon credits linked to seaweed-based carbon capture and storage are likely to be issued. These include:

- **Uncertainty related to blue carbon standards:** Concerns about the structure and integrity of the voluntary carbon market have put significant pressure on both the price of voluntary carbon credits and demand for the credits. Nature-based solutions have been under pressure due to uncertainty over additionality, permanence and the risk of double counting. The market for blue carbon credits is substantially smaller and less developed than that of land-based voluntary credits. Furthermore, seaweed-related carbon storage has its own issues, including uncertainty around permanence. Blue carbon standards have been issued by organisations such as Verra and Plan Vivo, The American Carbon Registry and The Gold Standard; however, they are mainly focused on mangrove and seagrass forests, tidal salt marshes and tidal wetlands, rather than on seaweed. For corporate interest in seaweed credits to accelerate, we believe that a strong set of seaweed standards needs to be developed. At present, a new methodology for this has been suggested by Oceans 2050 in collaboration with Verra (a nonprofit organisation focused on carbon credit standards). If adopted, this may trigger additional corporate interest in buying seaweed-based carbon credits.

- **Abatement costs will have to come down:** Nature-based carbon credits currently trade at a price of less than USD5 per tonne of CO2. However, according to a McKinsey study, among seaweed-related projects, only seaweed protection projects have an abatement cost relatively close to the current market price of nature-based carbon credits. Seaweed farming and restoration, on the other hand, have abatement costs of USD300 per tonne or more – not only much higher than current voluntary carbon prices, but also much higher than the almost USD100 per tonne of CO2 paid in the European compliance market. Abatement costs will have to come down aggressively to accelerate interest in seaweed related blue carbon credits.
- **Seaweed carbon storage may not be economical:** Whether carbon abatement costs for seaweed farming decline in the future will depend on the strength of the business model for a carbon-sequestration-only seaweed farm. Since the mid-1980s, academic papers have modelled different versions of seaweed farms with the aim of calculating the operating cost per kilogramme of wet-weight seaweed (estimates of this are shown in Figure 73). These calculations clearly suggest that in the absence of very strong government support or funding, carbon sequestration for a seaweed farm can only be an add-on activity rather than the core focus – selling one tonne of CO2 equivalent via a nature-based carbon credit currently yields only c.USD3.

Figure 73: Seaweed farm operating costs

Author	USDcost per dry tonne	USDcost per tCO2eq
Feinberg & Hock (1985)*	225	907
Valderrama et al (2015)*	400-900	1,610-3,630
van den Burg et al (2016)*	2,000	8,065
Camus et al (2019)*	610	2,460
Hasselstrom et al (2020)*	10,000	40,323
Kite-Powell et al (2022)*	200-300	806-1,210
Froehlich et al (2019)		71-27,222
Coleman et al (2022)		1,257-17,048

Source: Kite-Powell et al (2022), Froehlich et al (2019), Coleman et al (2022), Standard Chartered Research
* Converted into cost per tonne of carbon based on 24.8% carbon content (Duarte, 2017)

Regulation needs to be developed further

The establishment of solid regulatory frameworks is crucial to strong and sustainable development of the seaweed industry. These frameworks would not just support employment and livelihoods, but would also enhance the potential for seaweed to contribute to the SDGs. Strong governance frameworks would also help to attract capital to the sector.

In its 2022 State of World Fisheries and Aquaculture publication, the FAO pointed to the need for better frameworks, highlighting a number of shortcomings in aquaculture governance across countries. These include limited accountability, inadequate law enforcement, poor planning, and failure to address the negative environmental and public welfare impacts of some aquaculture systems.

In our discussions with industry participants, we frequently heard feedback that resonates with the FAO's observations. Farmers often note that governance, planning and approval processes are directed by different departments without clear coordination between them. This contributes to lengthy planning approval processes and inefficiencies.

The rapid expansion of the range of seaweed end markets and their sustainable characteristics is underappreciated by governments, in our view. More efficient and future-ready regulatory and licensing systems need to be developed in order to unlock the industry's potential, in our view.

Appendix

A financial model for seaweed farming

Figure 74: Base-case estimates for a hypothetical 10-hectare brown seaweed farm in a temperate region

	Year 1	2	3	4	5	6	7	8	9	10
Profit and loss account (USD)										
Revenue	**450,000**	**459,000**	**468,180**	**477,544**	**487,094**	**496,836**	**506,773**	**516,909**	**527,247**	**537,792**
Wet yield (kg/m)	15.0	15.2	15.3	15.5	15.6	15.8	15.9	16.1	16.2	16.4
Wet yield per year (kg)	1,500,000	1,515,000	1,530,150	1,545,452	1,560,906	1,576,515	1,592,280	1,608,203	1,624,285	1,640,528
Dry yield per year (kg)	300,000	303,000	306,030	309,090	312,181	315,303	318,456	321,641	324,857	328,106
Cost of goods sold										
Seeding related costs	95,050	96,951	98,889	100,866	102,883	104,940	107,039	109,179	111,362	113,588
Harvesting	20,075	20,476	20,885	21,301	21,727	22,160	22,603	23,054	23,514	23,984
Monitoring cost	9,050	9,231	9,415	9,602	9,794	9,989	10,189	10,392	10,599	10,811
Farm maintenance	11,200	11,424	11,652	11,886	12,123	12,366	12,613	12,865	13,123	13,385
Gross profit	314,625	320,919	327,339	333,888	340,568	347,381	354,330	361,419	368,649	376,024
% margin	70%	70%	70%	70%	70%	70%	70%	70%	70%	70%
General overhead	202,627	205,027	207,475	209,972	212,519	215,116	217,766	220,469	223,226	226,038
- Total staff cost	120,000	122,400	124,848	127,345	129,892	132,490	135,139	137,842	140,599	143,411
- Office and utilities	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
- Depreciation	32,627	32,627	32,627	32,627	32,627	32,627	32,627	32,627	32,627	32,627
EBITDA	**144,625**	**148,519**	**152,491**	**156,543**	**160,676**	**164,891**	**169,191**	**173,576**	**178,050**	**182,613**
% margin	32%	32%	33%	33%	33%	33%	33%	34%	34%	34%
Operating profit	**111,998**	**115,893**	**119,865**	**123,916**	**128,049**	**132,264**	**136,564**	**140,950**	**145,423**	**149,986**
% margin	25%	25%	26%	26%	26%	27%	27%	27%	28%	28%
Interest expenses	0	21,267	21,267	21,267	21,267	21,267	21,267	21,267	21,267	21,267
Pre-tax profit	**111,998**	**94,626**	**98,598**	**102,649**	**106,782**	**110,997**	**115,297**	**119,683**	**124,156**	**128,719**
Tax charge	28,000	23,656	24,649	25,662	26,696	27,749	28,824	29,921	31,039	32,180
Net profit	**83,999**	**70,969**	**73,948**	**76,987**	**80,087**	**83,248**	**86,473**	**89,762**	**93,117**	**96,539**
Cash flow statement	Year 1	2	3	4	5	6	7	8	9	10
EBIT	111,998	115,893	119,865	123,916	128,049	132,264	136,564	140,950	145,423	149,986
Tax on EBIT	28,000	28,973	29,966	30,979	32,012	33,066	34,141	35,237	36,356	37,496
Add back depreciation	32,627	32,627	32,627	32,627	32,627	32,627	32,627	32,627	32,627	32,627
NOPAT	116,625	119,546	122,525	125,564	128,663	131,825	135,050	138,339	141,694	145,116
CAPEX	708,900	0	0	0	0	0	0	0	0	0
Free cash flow	-592,275	119,546	122,525	125,564	128,663	131,825	135,050	138,339	141,694	145,116
Change in liabilities	354,450	0	0	0	0	0	0	0	0	0
Equity raising	354,450	0	0	0	0	0	0	0	0	0
Tax payment	28,000	23,656	24,649	25,662	26,696	27,749	28,824	29,921	31,039	32,180
Interest payment	0	21,267	21,267	21,267	21,267	21,267	21,267	21,267	21,267	21,267
Change in cash and equivalents	116,625	103,596	106,575	109,614	112,713	115,875	119,099	122,389	125,744	129,166
Cash at the start of the year	0	116,625	220,221	326,796	436,410	549,123	664,998	784,097	906,486	1,032,230
Cash at the end of the year	116,625	220,221	326,796	436,410	549,123	664,998	784,097	906,486	1,032,230	1,161,395
Balance sheet	Year 1	2	3	4	5	6	7	8	9	10
Fixed assets	676,273	643,647	611,020	578,393	545,767	513,140	480,513	447,887	415,260	382,633
Cash at year end	116,625	220,221	326,796	436,410	549,123	664,998	784,097	906,486	1,032,230	1,161,395
Total assets	**792,899**	**863,868**	**937,816**	**1,014,803**	**1,094,890**	**1,178,138**	**1,264,611**	**1,354,373**	**1,447,490**	**1,544,029**
Liabilities										
Debt	354,450	354,450	354,450	354,450	354,450	354,450	354,450	354,450	354,450	354,450
Equity	354,450	354,450	354,450	354,450	354,450	354,450	354,450	354,450	354,450	354,450
Retained earnings	83,999	154,968	228,916	305,903	385,990	469,238	555,711	645,473	738,590	835,129
Total shareholder funds	438,449	509,418	583,366	660,353	740,440	823,688	910,161	999,923	1,093,040	1,189,579
Total liabilities and equity	**792,899**	**863,868**	**937,816**	**1,014,803**	**1,094,890**	**1,178,138**	**1,264,611**	**1,354,373**	**1,447,490**	**1,544,029**

Source: Standard Chartered Research

Figure 75: Base-case estimates for a hypothetical 10-hectare red seaweed farm in a warmer region

	Year 1	2	3	4	5	6	7	8	9	10
Profit and loss account (USD)										
Revenue	**240,000**	**244,800**	**249,696**	**254,690**	**259,784**	**264,979**	**270,279**	**275,685**	**281,198**	**286,822**
Wet yield (kg/m)	4.0	4.0	4.1	4.1	4.2	4.2	4.2	4.3	4.3	4.4
Wet yield per year (kg)	800,000	808,000	816,080	824,241	832,483	840,808	849,216	857,708	866,285	874,948
Dry yield per year (kg)	160,000	161,600	163,216	164,848	166,497	168,162	169,843	171,542	173,257	174,990
Cost of goods sold										
Seeding related costs	16,967	17,303	17,646	17,996	18,353	18,717	19,088	19,466	19,853	20,246
Harvesting	17,117	17,455	17,799	18,150	18,509	18,874	19,247	19,627	20,015	20,410
Monitoring cost	22,800	23,253	23,715	24,186	24,667	25,157	25,657	26,167	26,687	27,218
Farm maintenance	10,400	10,608	10,820	11,037	11,257	11,482	11,712	11,946	12,185	12,429
Gross profit	172,717	176,182	179,716	183,321	186,998	190,749	194,575	198,478	202,458	206,519
% margin	72%	72%	72%	72%	72%	72%	72%	72%	72%	72%
General overhead	105,293	106,093	106,909	107,742	108,591	109,457	110,340	111,241	112,160	113,097
- Total staff cost	40,000	40,800	41,616	42,448	43,297	44,163	45,046	45,947	46,866	47,804
- Office and utilities	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000
- Depreciation	25,293	25,293	25,293	25,293	25,293	25,293	25,293	25,293	25,293	25,293
EBITDA	**92,717**	**95,382**	**98,100**	**100,872**	**103,701**	**106,586**	**109,528**	**112,530**	**115,592**	**118,715**
% margin	39%	39%	39%	40%	40%	40%	41%	41%	41%	41%
Operating profit	**67,423**	**70,088**	**72,806**	**75,579**	**78,407**	**81,292**	**84,235**	**87,237**	**90,299**	**93,422**
% margin	28%	29%	29%	30%	30%	31%	31%	32%	32%	33%
Interest expenses	0	13,467	13,467	13,467	13,467	13,467	13,467	13,467	13,467	13,467
Pre-tax profit	**67,423**	**56,621**	**59,339**	**62,112**	**64,940**	**67,825**	**70,768**	**73,770**	**76,832**	**79,955**
Tax charge	16,856	14,155	14,835	15,528	16,235	16,956	17,692	18,442	19,208	19,989
Net profit	**50,568**	**42,466**	**44,505**	**46,584**	**48,705**	**50,869**	**53,076**	**55,327**	**57,624**	**59,966**
Cash flow statement	Year 1	2	3	4	5	6	7	8	9	10
EBIT	67,423	70,088	72,806	75,579	78,407	81,292	84,235	87,237	90,299	93,422
Tax on EBIT	16,856	17,522	18,202	18,895	19,602	20,323	21,059	21,809	22,575	23,355
Add back depreciation	25,293	25,293	25,293	25,293	25,293	25,293	25,293	25,293	25,293	25,293
NOPAT	75,861	77,859	79,898	81,978	84,099	86,263	88,470	90,721	93,017	95,360
CAPEX	448,900	0	10,000	0	0	10,000	0	0	10,000	0
Free cash flow	-373,039	77,859	69,898	81,978	84,099	76,263	88,470	90,721	83,017	95,360
Change in liabilities	224,450	0	0	0	0	0	0	0	0	0
Equity raising	224,450	0	0	0	0	0	0	0	0	0
Tax payment	16,856	14,155	14,835	15,528	16,235	16,956	17,692	18,442	19,208	19,989
Interest payment	0	13,467	13,467	13,467	13,467	13,467	13,467	13,467	13,467	13,467
Change in cash and equivalents	75,861	67,759	59,798	71,877	73,999	66,162	78,369	80,621	72,917	85,259
Cash at the start of the year	0	75,861	143,620	203,418	275,295	349,294	415,456	493,826	574,446	647,363
Cash at the end of the year	75,861	143,620	203,418	275,295	349,294	415,456	493,826	574,446	647,363	732,623
Balance sheet	Year 1	2	3	4	5	6	7	8	9	10
Fixed assets	423,607	398,313	385,020	359,727	334,433	321,140	295,847	270,553	257,260	231,967
Cash at year end	75,861	143,620	203,418	275,295	349,294	415,456	493,826	574,446	647,363	732,623
Total assets	**499,468**	**541,933**	**588,438**	**635,022**	**683,727**	**736,596**	**789,672**	**845,000**	**904,623**	**964,590**
Liabilities										
Debt	224,450	224,450	224,450	224,450	224,450	224,450	224,450	224,450	224,450	224,450
Equity	224,450	224,450	224,450	224,450	224,450	224,450	224,450	224,450	224,450	224,450
Retained earnings	50,568	93,033	137,538	184,122	232,827	283,696	336,772	392,100	449,723	509,690
Total shareholder funds	275,018	317,483	361,988	408,572	457,277	508,146	561,222	616,550	674,173	734,140
Total liabilities and equity	**499,468**	**541,933**	**586,438**	**633,022**	**681,727**	**732,596**	**785,672**	**841,000**	**898,623**	**958,590**

Source: Standard Chartered Research

Disclosures appendix

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