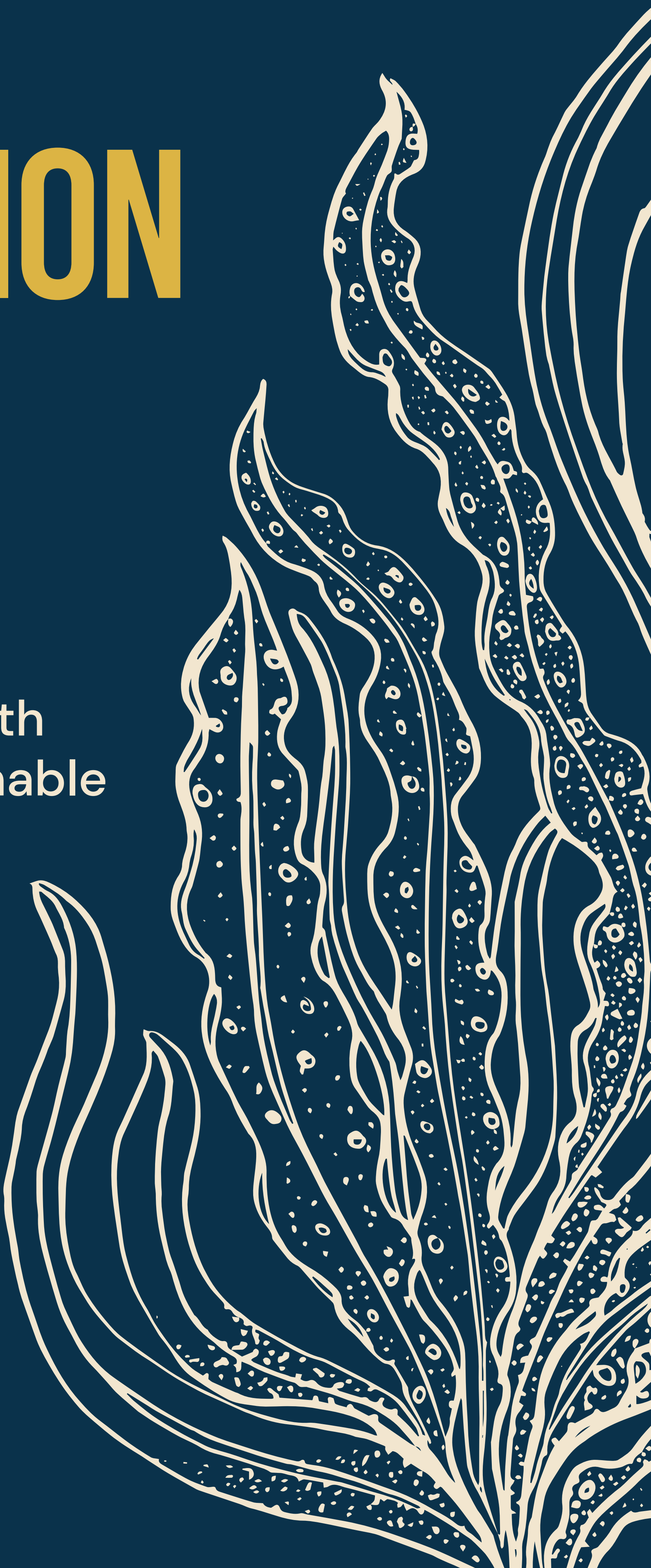
HIDDEN CHAMPION OF THE OCEAN

Seaweed as a growth engine for a sustainable European future



SEAWEED for EUROPE

Funded by SUN Institute
Environment & Sustainability
Initiated by Deutsche Post Foundation

Contents

SEAWEED for EUROPE

www.seaweedeurope.com
seaweedeurope@systemiq.earth

Preface

Europe is at crossroads. The health of our ocean is at peril, climate change consequences are increasingly manifesting, inequalities are on the rise, the economic future is uncertain. At the same time, the European Green Deal constitutes the most ambitious political package to build a greener, more resilient, and fair Europe.

Achieving this ambition will require the development of new and regenerative industries. Seaweed (macroalgae) is a promising ocean material which could support this agenda. While Europe's seaweed sector today remains small, the conditions are favourable to grow it into a vibrant, innovative and sizeable industry with many social and environmental benefits. The Seaweed for Europe coalition was launched in 2020 to catalyse such change and unlock seaweed's remarkable potential.

Seaweed for Europe brings together stakeholders from across the seaweed value chain, spanning industry associations, investors, farmers, processors, technology providers, academia, and thought leaders. Today, we count more than 40 organisations from over 10 European countries among our members and continue to grow. Our members are at the centre of the Coalition's work, shaping our agenda and bringing our vision for Europe's seaweed industry to life.

To achieve Seaweed for Europe's objectives, a central focus of the Coalition is to elevate the seaweed profile to the right audiences - a critical first step in addressing existing impediments to the scaling of a sustainable industry in Europe. An on-the-ground action programme driven by our members is a key component of this process.

This report has endeavoured to articulate Seaweed for Europe's strategic ambitions. In quantifying the extraordinary economic, social and environmental potential of the European seaweed industry, the report seeks to highlight the significance of the opportunity seaweed presents to contribute to the SDGs and the Paris Agreement. The report also identifies the principles that must lie at the heart of the industry if it is to be sustainable, and prioritises actions to be undertaken by investors, policy, investment and business decision-makers to address the industry's main challenges and unlock sustainable and equitable growth.

Importantly, the report also contributes to the wider conversation around seaweed taking place throughout Europe and the world. The High Level Panel for a Sustainable Ocean Economy, made up of fourteen serving heads of governments, has for instance already recognised seaweed as a promising ocean-based solution to help counteract climate change and support the SDGs. Similarly, the Seaweed Manifesto published by the UN Global Compact in June this year spoke out in favour of scaling the industry. Through this report, this dialogue can be strengthened, reach new ears and lead to tangible impact.

Seaweed for Europe has taken up the baton to shine a spotlight on the hidden champion seaweed. We hope that readers of this report will embark on this entrepreneurial and thrilling, but also critical journey together with us.

Adrien Vincent

Programme Director, Seaweed for Europe
Ocean Lead at SYSTEMIQ

Foreword

The world is increasingly coming to the realisation that the foundations upon which our societies and economies are built are flawed. The systems that have given us so much in the past are now pushing both human and planetary boundaries to their limits, risking catastrophic outcomes.

The COVID-19 crisis serves as just one example which painfully highlights the negative impact the gross mismanagement of our relationship with nature can have. The pandemic has undoubtedly shaken the world, exposing the weakness of our existing systems throughout many countries: unable to withstand unexpected shocks, deeply inequitable and based on a continuous over-exploitation of planet Earth and its resources. It has also demonstrated an urgent need to rethink the values by which we live.

As the world starts to build back, there is an opportunity to place the protection of human and planetary boundaries at the heart of our system. There is an opportunity to develop a "new normal" which has strong yet adaptable foundations and is based on solutions promoting social justice as well as more sustainable green growth.

While this "normal" has been the focus of many recovery discussions, the contribution the ocean could make towards creating this future has been largely overlooked – in spite of the central importance for human and planetary health of the ecosystem services it provides. In fact, the ocean is still very much perceived as a mere "victim", of climate change (causing warming, acidification and deoxygenation), of overfishing (resulting in the depletion of fish stocks) and of pollution (through ocean plastics and eutrophication). In reality, however, the ocean may be a valuable piece of the puzzle, providing promising solutions which contribute to sustainable recovery and drive the restoration and protection of its own health at the same time.

This is especially true in Europe, where policy support to "build back better" is laying the groundwork for ocean-based champions to emerge. As a result, Europe has the potential to become a blue leader, not just in large industrial sectors such as shipping or energy generation, but equally in nature-based solutions stemming from the ocean.

Seaweed is a prime example of such a solution. It is a regenerative material par excellence, with unique properties which are crucial to the ocean ecosystem. In contrast to land-based agricultural crops, seaweed requires neither external inputs such as fertiliser nor cleared land space to grow. In addition, seaweed can be used in a myriad of innovative and sustainable product applications with a range of health and environmental benefits. A strong European seaweed industry can boost economic growth, for example by channelling investment into coastal communities or by creating new employment opportunities. Yet the potential of seaweed has so far been largely overlooked.

This report seeks to shine a spotlight on this hidden champion. We are delighted to be part of this journey as Co-Chairs of the Coalition, and we invite you to join us in elevating the seaweed industry in Europe to a more prominent position.

Maria Damanaki

Special adviser for SYSTEMIQ and Paradise Foundation, Former commissioner, Maritime Affairs and Fisheries. European Commission

Maren Hjorth Bauer

Managing Partner and Founder, Fynd Ocean Ventures. Former CEO and Co-Founder, Katapult Ocean

Vidar Helgesen

Special Envoy for the Ocean of the Norwegian Ministry of Foreign Affairs. Former Minister of Climate and Environment, Minister of European Affairs

In support of the report

“The ocean holds tremendous opportunities for boosting jobs and the economy while at the same time helping and healing the planet. This report highlights the new, sustainable business opportunities that seaweed can represent, and I welcome this contribution to increasing our awareness of ocean health and wealth.”

Erna Solberg, Prime Minister of Norway and Co-Chair of the High Level Panel for a Sustainable Ocean Economy

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“A healthy and sustainable ocean economy is absolutely necessary for the attainment of the UN’s Sustainable Development Goals and a successful response to the looming Climate Crisis – no healthy planet without a healthy ocean! This new report makes clear that the seaweed industry in Europe can be an integral part of that story, bringing with it sustainable and resilient jobs, regenerated ecosystem services and solid business opportunities. I’m pleased to see that the report offers the necessary systemic guiding principles to make that so, along with a timely roadmap to unlock the potential of a sustainable seaweed sector in Europe.”

Peter Thomson of Fiji, United Nations Secretary General’s Special Envoy for the Ocean

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“Seaweed addresses some of the core challenges we currently face, offering promising solutions which can support green recovery. This report offers a fresh perspective on a truly promising champion for a successful and green post-covid Europe”

Janez Potočnik, Co-Chair of the International Resource Panel, Member of The Club of Rome, SYSTEMIQ Partner, and former European Commissioner for Science & Research and for the Environment

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“We all need to break our addiction to fossil fuels and learn to use carbon-based materials already above the ground and in oceans. Seaweed is a high-potential renewable material that can help produce more sustainable and better performing chemicals and packaging at the scale needed. This report provides the economic and environmental case for making seaweed a household name, as well as a household product.”

Peter ter Kulve, President Unilever Home Care

“This report shows seaweed will be the resource of the XXI century. It will change our lives as much as cacao and coffee changed the life of our ancestors in the XIX century”.

Tiago Pitta e Cunha, CEO of the Oceano Azul Foundation

“The next ten years will determine the future of our oceans. Regenerative seaweed farming can be a powerful means to restore abundance to our oceans and mitigate the impact of climate change. Oceans 2050 is looking forward to working with Seaweed for Europe to translate the “Hidden Champion” report into reality, so that a regenerative seaweed industry can fully contribute to a prosperous, biodiverse and resilient Europe”.

Alexandra Cousteau, Founder, Oceans 2050

“Sustainable Seaweed is Europe’s next hidden champion. We are only starting to understand the value of seaweed as a climate-friendly source of food, feed or biomaterial. It allows us to use the European seas and create income whilst storing CO2 and restoring fisheries. Asian countries have started to recognize the promise of seaweeds. Now it’s Europe’s turn.”

Martin R. Stuchtey, Co-Founder of SYSTEMIQ and former Director of the McKinsey Center for Business and Environment

“Seaweed is a true ‘superfood’. As a chef I add it to a wide variety of dishes in order to bring out the full flavour of culinary creations. I prefer local sourcing, and so I produce my own gourmet seaweed of the finest quality, sustainably farmed and responsibly harvested in the islands of Austevoll on the Norwegian West Coast. It is a dense source of iodine, fibre, vitamins C, K and B-12, antioxidants and other essential nutrients. I fully agree with the essence and title of this report: Seaweed is a hidden champion of the ocean! It’s a natural solution that helps biodiversity, health and job creation. And, not to forget: taste.”

Ørjan Johannessen, winner of the 2015 Bocuse d’Or (using seaweed!) and product manager at www.flytseaweed.com

Acknowledgments

This report was produced with the support of the SUN Institute Environment & Sustainability and authored by the Secretariat of Seaweed for Europe.

About the SUN Institute Environment & Sustainability

The SUN Institute was established in 2014 by the Deutsche Post Foundation to strengthen its international activities in supporting institutions, programmes and projects dealing with the environmental challenges and opportunities of globalisation and enhanced cross-border activities.

Find out more at: **www.sun-institute.org**

About Seaweed for Europe

Seaweed for Europe is a Coalition seeking to accelerate and scale the European seaweed industry by driving innovation and investment, with the ultimate aim of unlocking significant economic, environmental and social benefits. The Coalition brings together a range of stakeholders from the seaweed value chain, the investment world, and science and civil society thought leaders. It is headed by a Coalition Secretariat run by SYSTEMIQ as well as Co-Chairs Maria Damanaki, Maren Hjorth Bauer and Vidar Helgesen.

Find out more at: **www.seaweedeurope.com**

About SYSTEMIQ

SYSTEMIQ Ltd. is a certified B Corp with offices in London, Munich, Jakarta and Amsterdam. The company was founded in 2016 to drive the achievements of the Paris Agreement and the United Nations Sustainable Development Goals by transforming markets and business models in three key economic systems: regenerative land use and ocean, low carbon energy, and materials and the circular economy.

Find out more at: **www.systemiq.earth**

About the authors of this report

Adrien Vincent, Programme Director Seaweed for Europe, Ocean Lead at SYSTEMIQ

Anna Stanley, Programme Manager Seaweed for Europe, Project Manager at SYSTEMIQ

Jennifer Ring, Programme Associate Seaweed for Europe, Modelling Expert at SYSTEMIQ

The authors are also grateful to the members of Seaweed for Europe who have contributed to this report with invaluable insights.

This report was created within the remit of the authors' work for the Seaweed for Europe Coalition. The opinions, findings and recommendations expressed herein reflect the authors' views only and shall not be taken to have the endorsement nor reflect the views of any of the aforementioned organisations or individuals and their affiliated organisations.

Editorial, Design and Communications

Editorial: Ho Ting Chung and Evan Jeffries, Communications INC
Design: David Hughes, Josh Gutteridge, Andrei Vasyliev and Paula Mastrangelo, Regency Creative
Communications: Tugce Balik, Theo Gott and Sun Oh, SYSTEMIQ

The authors would like to thank the following individuals for their proactive, detailed and thoughtful input to this report:

Efthalia Arvaniti, SUBMARINER Network
Tobias Baehr, BlueCs
Michèle Barbier, Institute for Science & Ethics
Maren Hjorth Bauer, Fynd Ocean Ventures, Seaweed for Europe
Charlie Bavington, Oceanium
Darcy Bradley, Bren School of Environmental Science & Management, University of California, Santa Barbara
Maximilian Bucher, SYSTEMIQ
Megan Reilly Cayten, Oceans 2050
Mélanie Cueff, Wealsea
Santiago Cortes, Amerra Capital
Maria Damanaki, Paradise International Foundation, Seaweed for Europe
Angelo Demeter, Volta Greentech
Vincent Doumeizel, Lloyd's Register Foundation, UN Global Compact
Marco van Duijvenvoorde, SeaFlavours
Petrissa Eckle, sus.lab, ETH Zurich
Antoine Erwes, International Blue Cooperative
Pierre Erwes, BioMarine
Jon Funderud, Seaweed Energy Solutions
Vidar Helgesen, Norwegian Ministry of Foreign Affairs, Seaweed for Europe
Daniel Hooft, Kelp Blue
Stefan Kraan, The Seaweed Company
Felix Leinemann, European Commission, DG Mare
Tim Lemeer, Barentz
Albrecht Matuschka, Matuschka Group
Angela Mead, Biome Algae Ltd.
Gunvor Øie, SINTEF
Pierre Paslier, Notpla
Philippe Potin, IDEALG & GENIALG, Station Biologique de Roscoff, CNRS Sorbonne Université
Eva Ramirez-Llodra, REV Ocean
Olivier Raybaud, Blue Oceans Partners
Alex Rogers, REV Ocean
Eva Helen Rognskog, Satpos
Morten Rosse, SYSTEMIQ
Philipp Saumweber, Sunridge Partners
Karen Scofield Seal, Oceanium
Jorunn Skjermo, SINTEF
Martin Stuchtey, SYSTEMIQ
Maris Stulgis, European Commission, DG Mare
Fiona Trappe, Seaweed Alliance
Mikael Westerlund, Origin by Ocean

Suggested citation

Vincent, A., Stanley, A. and Ring, J., "Hidden champion of the ocean: Seaweed as a growth engine for a sustainable European future", Seaweed for Europe, 2020

Hidden champion at a glance

Seaweed (macroalgae) provides a range of product applications...

- Animal feed
- Food
- Pharmaceuticals & nutraceuticals
- Additives
- Bio-packaging
- Cosmetics
- Biostimulants
- Biofuels
- Valorisation of ecosystem services

...which could scale the European seaweed industry,...

€9.3bn
potential market value by 2030

(of which **30%** supplied by seaweed grown in Europe)

...creating significant environmental benefits...

Mitigation of
>5m t[1]
of CO_2e emissions p.a.

Absorption of
20,000 t of nitrogen
2,000 t of phosphorus
from the ocean p.a.

Provision of **ecosystem services** (food, habitat, nursery ground for marine species)

No need for freshwater, fertiliser or cleared land

...and strong social impact.

Creation of
115,000 jobs
for different skill and experience profiles

Revitalisation of coastal communities

Improvement of diets and general **health**

Europe is perfectly suited for such a scale up.

Ideal growing conditions with nutrient-rich, cold waters

Burgeoning innovation community including start-ups and SME players across the value chain

Existing and fast-growing demand for seaweed-based products and ingredients

Strong alignment with European Green Deal objectives and priorities

To deliver this potential, the nascent European seaweed industry must accelerate and significantly grow its production capacity.

From
~300.000 t
of fresh weight seaweed produced today

to
>8m t
of fresh weight seaweed produced in 2030

By following five key guiding principles, the industry can become a pioneer for green and equitable growth and play an integral part in our "new normal".

- Embrace a system view
- Make the system resilient
- Share benefits fairly among stakeholders
- Be guided and informed by science
- Measure and monitor success using holistic metrics

Targeted action in six priority areas can put this industry on the right track to fully unlock this promising potential.

1. Optimise seaweed farming licensing process
2. Attract public and private investors to the seaweed space
3. Create a strong and collaborative stakeholders network
4. Establish robust safety standards and a comprehensive certification system
5. Raise awareness on the benefits and potential of seaweed
6. Leverage science to accelerate innovation

1 Further research needed to determine full industry potential. Due to limited data availability, figure only includes mitigation potential for animal feed, bio-packaging and biofuel.
2 Based on consideration of every part-time role as a separate job. Equivalent to 85,000 FTE

Introduction

While perceptions differ around the world, seaweed is often considered as something of a nuisance by Europeans, its presence tarnishing pristine beaches or disturbing ocean swimmers. Beyond its use in Asian cuisine, many Europeans lack knowledge on the potential applications or benefits of this ocean material. On closer investigation, however, it quickly becomes apparent that seaweed is indeed rather more of a hidden champion in this part of the world, underappreciated and not fully understood.

In the simplest terms, seaweed (macroalgae) is a plant-like organism which grows in a variety of forms and colours in the ocean as well as in freshwater environments (Andersen & Lewin, 2020). It is rich in minerals, vitamins and polysaccharides, with some species also containing larger amounts of amino acids, proteins and fatty acids (Leandro, Pereira & Gonçalves, 2020). Although there are a vast range of species – with estimates suggesting 72,500 known species (and many more assumed) (Guiry, 2012) – production centres around roughly a dozen, including well-known species such as Japanese kelp, nori and wakame (FAO, 2018; FAO, 2020).

Within the ocean, seaweed plays a central role in providing critical ecosystem services. It forms an integral part of a complex food web (Pereira, 2015; Andersen & Lewin, 2020) and offers habitat, nursery grounds and shelter for different ocean species (Smale, Burrows, O'Connor, & Hawkins, 2013; Bertocci, Araújo, Oliveira & Sousa–Pinto, 2015). Underwater forests of kelp in fact are considered one of the planet's most productive habitats (Mann, 1973; Smale, Burrows, O'Connor & Hawkins, 2013; Barbier, et al., 2019).

In addition, seaweed is a natural protector, containing the force of the ocean by dissipating wave energy and preventing coastal erosion (Duarte, Wu, Xiao, Bruhn & Krause-Jensen, 2017).; Barbier, et al., 2019). Seaweed also absorbs a range of excess inorganic nutrients from the ocean, including nitrogen and phosphorus (World Bank Group, 2016; Barbier, et al., 2019), as well as other compounds such as CO_2 (Krause-Jensen & Duarte, 2016; Ortega, et al., 2019).

Its biochemical composition and properties make seaweed an equally valuable material away from the ocean. Seaweed is used for a growing range of applications ranging from food products and animal feed to cosmetics and chemicals for various industries. Many of these applications provide sustainable, low-carbon and less harmful alternatives to existing options, offering diverse environmental and health benefits. Figure 1 shows some examples of the most significant and developed applications for seaweed, highlighting their respective benefits.

> "Seaweed is a true 'superfood'. As a chef I add it to a wide variety of dishes in order to bring out the full flavour of culinary creations. Seaweed is a hidden champion of the ocean! It's a natural solution that helps biodiversity, health and job creation. And, not to forget: taste."
>
> Ørjan Johannessen, winner of the 2015 Bocuse d'Or (using seaweed!) and product manager at www.flytseaweed.com

Figure 1 – Applications and benefits of seaweed

Health benefit Environmental benefit

Segment	Example application	Primary functions	Benefits
Food	Raw salads, crisps, spaghetti, burgers	Source of energy, protein and vitamins	Supports healthier diets due to high minerals, vitamins, protein and fibre contents Lower environmental footprint than animal or land-based alternative protein sources
Additives	Gelatine substitutes, processed meat and dairy	Provision of thickening, stabilising and emulsifying properties	Natural and vegan-friendly Lower environmental footprint than animal-based alternatives
Animal feed	Livestock feed supplements, aquafeed supplements, pet food additives	Promotion of positive immune response and gut health; improvement of digestive processes	Improvement in animal health, production yields Reduction of methane emissions from livestock
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
Pharmaceuticals & nutraceuticals	Gastrointestinal protectors, biodegradable wound care products / nutrient health supplements	Source of bioactive and nutrient-rich ingredients	Disease prevention and treatment Natural health enhancers
Cosmetics	Anti-aging moisturisers, toothpaste	Source of bioactive and nutrient-rich ingredients; provision of thickening, stabilising and emulsifying properties	Natural and vegan-friendly Supports skin health
Bio-packaging	Packaging, coatings and plastic films for food containers	Source of marine-safe and compostable plastic molecules	Replacement of substances causing environmental damage in production (fossil fuel) and after end-of-life (ocean leakage)
Biofuels	Biodiesel for use in cars	Source of energy	Replacement for fossil fuels or land-intensive biofuels Made from seaweed processing by-products

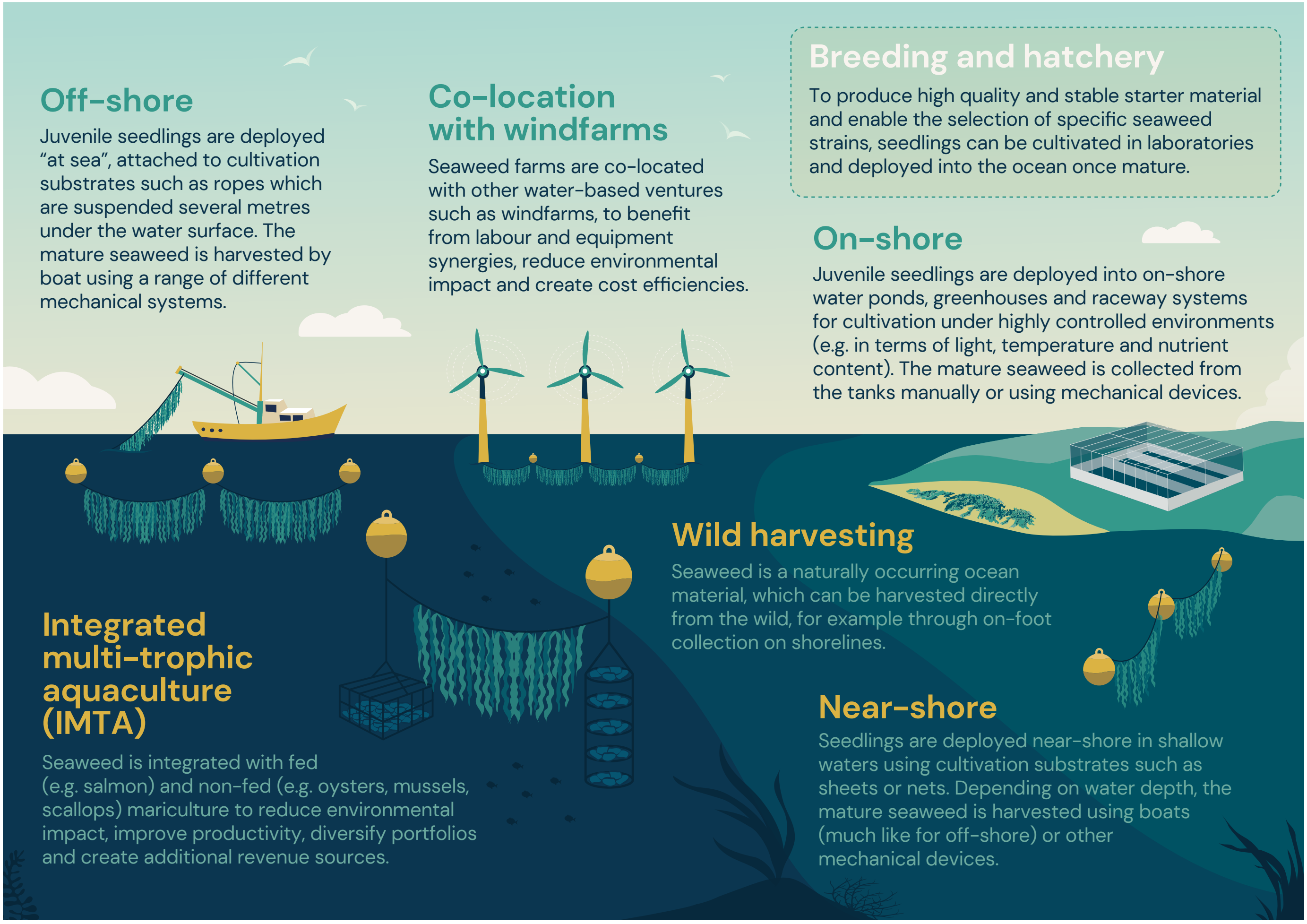
Note: This list seeks to highlight some of the most exciting applications only. Seaweed can be used in many more promising and innovative applications, including textile fibres, laundry detergents and construction materials.

Source: Rhein-Knudsen, Ale, & Meyer, 2015; Fleurence & Levine, 2016; Li, et al., 2016; Kinley, de Nys, Vucko, Machado, & Tomkins, 2016; Machado, Magnusson, Paul, Kinley, & de Nys, 2016; Maia, 2016; Bleakley & Hayes, 2017; Kinley, et al., 2020; Leandro, Pereira, & Gonçalves, 2020

Beyond these examples, seaweed has many more innovative applications which are still being developed or scaled, including textile fibres, laundry detergents, construction materials, and biochar for soil improvement and carbon dioxide removal (Roberts, Paul, Dworjanyn, Bird & de Nys, 2015; Praveena & Muthadhi, 2016; Ross, 2017; Gatten, 2020).

The seaweed needed to create these different products can be obtained in a variety of ways. While seaweed is a naturally occurring material which can be simply harvested from the wild, global trends seem to indicate an aquaculture-centred future, with seaweed grown onshore, near-shore and offshore or in integration with other ocean uses such as complementary aquaculture operations or windfarms (Figure 2).

Figure 2 – Different types of seaweed production



Source: Netalgae, 2012; Xinxin, et al., 2013; Cottier-Cook, et al., 2016; World Bank Group, 2016; Barbier, et al., 2019

Unlike for equivalent land-based materials, the different types of production generally do not require any freshwater, fertiliser or other external inputs. There is also no need to repurpose or clear land – a necessary practice for agricultural crops which often results in the disruption and displacement of biodiversity or, in the worst cases, its complete loss (for example through deforestation) (SAPEA, 2017). The regenerative nature of seaweed – i.e. the way in which it supports ocean health, biodiversity and ecosystem services – makes it a particularly promising ocean solution.

Given the benefits of seaweed and its growing range of applications, it is unsurprising that the global seaweed market is on an upward trajectory. Although market size estimates and predictions vary considerably across sources, there is a general consensus that the industry has been and will continue to grow exponentially (FAO, 2018; Barbier, et al., 2019; Fortune Business Insights, 2019; FAO, 2020; Grand View Research, 2020; Lloyd's Register Foundation, 2020). According to the Food and Agriculture Organization of the United Nations the seaweed market more than tripled between 2000 and 2018, reaching

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> Martin R. Stuchtey, Co-Founder of SYSTEMIQ and former Director of the McKinsey Center for Business and Environment

32.4 million tonnes of production with a value of US$13.3 billion (€11.3 billion) in 2018. The majority of the seaweed – 31.4 million tonnes – was derived from cultivation, while only 0.9 million tonnes were harvested from the wild (FAO, 2020). Asia is the clear industry front-runner, accounting for more than 99% of seaweed production in 2018 (FAO, 2020).

This growth trend is driven by the expanding markets for seaweed-based foods and food additives (hydrocolloids). In 2019, 77% of seaweed produced globally was used for application in human consumption (Grand View Research, 2020). As consumers are increasingly focused on a healthier and more sustainable diet, and with a growing appreciation of the health benefits associated with seaweed, this market is expected to continue to expand significantly (FAO, 2018; Grand View Research, 2020).

Further market growth is also likely to be driven by a changing perception of our current way of life. A continuation of existing unsustainable food and land use practices, for example, could severely threaten natural resources, biodiversity, food security and socioeconomic development (EAT-Lancet Commission, 2019; The Food and Land Use Coalition, 2019). In addition, annual flows of non-degradable plastics into the ocean are projected to triple by 2040 if no serious action is taken (Lau, et al., 2020). These findings, together with the recent events surrounding COVID-19, are triggering an increasing realisation that it is essential to move towards new solutions which protect rather than destroy the planet and what it offers to humankind. As we progress towards rebuilding the system we live in, the inclusion of solutions like seaweed will undoubtedly continue to drive growth in the seaweed market.

Today, global growth in the seaweed market is mostly driven by Asian markets (Camia, et al., 2018). While seaweed has been used in coastal communities around the world for centuries, human consumption of seaweed has been and continues to be particularly high in this region (Fleurence & Levine, 2016; SAPEA, 2017; Barbier, et al., 2019). In addition, the steady growth of the hydrocolloid industry in Southeast Asia by some 2-3% per annum is further contributing to this increase (FAO, 2018). As a result, the industry in Asia has evolved to become quite sophisticated, relying heavily on aquaculture to meet demand. China – the leading producer of farmed seaweed both in terms of value and volume, with a 57% global market share in 2018 – started cultivation as early as the 1950s. In smaller coastal communities, aquaculture production of this kind has become a reliable alternative source of income, with low set-up costs and without negative impacts on existing fisheries (FAO, 2018).

The seaweed industry in Europe could not be more different. With a strong focus on harvesting seaweed from the wild, the aquaculture industry is still very much at a nascent stage, although it began back in the mid-1980s (Camia, et al., 2018; Barbier, et al., 2019). While the Asian market has grown significantly over the past decade, production in Europe has plateaued. Wild harvesting in particular has stagnated, due among other reasons to excessive harvesting and changing weather patterns (Camia, et al., 2018; Barbier, et al., 2019). The development of the aquaculture industry in turn has been hindered by factors such as a complex licensing processes, a lack of cost-efficient technologies, missing industry infrastructures and an absence of value chain integration, as well as limited investment (Netalgae, 2012; Barbier, et al., 2019; Lloyd’s Register Foundation, 2020). In 2015, only 1,450 tonnes of seaweed were cultivated through aquaculture – however, even the additional 294,744 tonnes harvested from the wild seem a mere footnote compared to global figures (FAO, 2018).

Despite its current position within the global seaweed market, Europe is in fact perfectly placed to develop a strong regional industry centred around aquaculture production. Nutrient-rich and cold waters provide ideal growing conditions (Froehlich, Afflerbach, Frazier & Halpern, 2019). In addition, Europe's coastal regions have been assessed as "high opportunity" based on factors such as the environmental and socioeconomic benefits that could be derived from the development of such an industry (Theuerkauf, et al., 2019). As a top global importer of seaweed products in terms of value (US$613 million in 2016 (€554 million)), there is clearly a strong demand for seaweed in Europe which is only set to increase in line with health and sustainability trends (FAO, 2018). The number of European food and drink products that include seaweed, for example, grew by a factor of 2.5 between 2011 and 2015 (Mintel, 2016).

The range of solutions offered by an expanding seaweed industry in Europe are also closely aligned with ongoing efforts to restore ocean health, create a more sustainable ocean economy and reconcile the post-COVID recovery with the EU Green Deal. Driven by a burgeoning tech and innovation community which is seeking to optimise the way seaweed is produced, processed and used, seaweed could play a central role in the European Commission's objective to develop cleaner, low-carbon and technology-enabled industries and address the significant shortcomings of the existing agricultural model. In doing so, the industry could also boost local economies and provide new employment opportunities (Barbier, et al., 2019).

With all it has to offer, seaweed could thus become a paradigm for a sustainable ocean industry. In demonstrating that this really is within reach, this report makes the case for developing the European seaweed industry. It focuses on:

Why (Chapter I)

Different growth scenarios are outlined to show the contribution seaweed could make to the European economy and job market, as well as the associated environmental co-benefits this could create.

What (Chapter II)

A vision of a scaled 2030 seaweed industry provides the basis for five key guiding principles to ensure sustainable, fair and resilient growth.

How (Chapter III)

Priority areas which need to be addressed to create the pre-conditions for investment and growth are identified. On this basis, the Seaweed for Europe 2020/21 Action Programme is introduced.

CHAPTER I

The case for seaweed: an overlooked opportunity for Europe

While the dynamic and fast-growing global seaweed market has increasingly been attracting attention, the European industry remains largely overlooked. As a result, knowledge on the true economic, social and environmental potential of this vibrant albeit nascent market is limited. Quantifying this potential, however, is essential for expansion, an important tool to foster awareness, inform policymakers and attract investment. To close the knowledge gap, this chapter defines the potential of the industry in 2030.

The European seaweed industry in 2030 – an overview

The seaweed industry in Europe represents a remarkable economic, social and environmental opportunity (Figure 3). The European market for seaweed in 2030 has the potential to drive a multi-billion-euro industry, worth up to €9.3 billion. Under the right conditions, European producers could capture around one-third of this market (€2.7 billion), generating 85,000 jobs. In addition, seaweed could mitigate up to 5.4 million tonnes of CO_2e emissions annually, remove thousands of tonnes of nitrogen and phosphorus each year from eutrophied European coastal waters, contribute to preserving biodiversity, and help protect European coasts from erosion.

Figure 3 – Main modelling outputs and key results

1 What is the potential **market size** for seaweed in Europe?

- Up to **€9.3bn** across 8 main segments
- **30% of this market addressable** by European supply (the rest by imported seaweed)

2 What **European supply** is required to meet demand?

- Up to **8.3 million freshweight tonnes** of seaweed produced
- Production to be supplied by up to **27,300 hectares farming capacity**, of which
  - 7,700-26,300 hectares of marine farms
  - 300-1,000 hectares of onshore farms

3 How many **jobs** could be created in the process?

- Up to **85,000 FTEs** (full time employee equivalent)[1], of which
  - 38,000 direct
  - 28,000 indirect
  - 19,000 induced

4 What are the **environmental impacts**?

- Net mitigation: Up to **5.4 million tonnes CO2e** (based on direct sequestration and emissions displaced by end-use products)[2]
- Nutrient absorption: Up to **20,000 tonnes of N** and **2,000 tonnes of P** removed per annum
- Additional ecosystem services and contribution to sustainable development

1. Equivalent to 115,000 discrete jobs when full time and temporary roles are counted individually. 2. With potential for further avoidance from additional segments, pending research.
Note: Values are for high ambition level - see Appendix for low and moderate ambition level outcomes.

Modelling methodology

The object of the modelling for this report was to derive reliable and credible numbers which provide an insight into the potential size of the European seaweed industry in 2030 and underline the strength of the business case for its development. We chose 2030 as a time-horizon on the basis of the exponential growth the global industry has witnessed in the last decade and the view that – with the right support and enabling conditions – the seaweed industry in Europe could change equally rapidly.

All 2030 numbers stated in this report are based on knowledge of the market today, combined with assumptions about how the dynamics that have shaped the market thus far may evolve moving into the next decade. While the modelling outcomes are not forecasts, and should not be treated as such, they do offer an insight into what might be possible for the industry if certain conditions are met.
The modelling sought to deliver on an ambitious scope. Accordingly, four principles were applied to ensure a balance between breadth and depth:

- An 80/20 approach was taken, with a view to prioritising the most significant outcomes and focusing on strengthening their reliability.
- Smart assumptions were made on the basis of extensive research in scientific journals, industry publications, expert interviews and other relevant sources.
- Numbers were iterated regularly in short review cycles with a range of industry experts as well as external stakeholders with expertise in the broader ocean and finance fields.
- Where appropriate, outcomes were triangulated using different calculation methods to increase their robustness.

1. An attractive multi-billion-euro seaweed market in 2030 in Europe

There is no doubt that to view the seaweed sector purely through an economic lens is to take an impoverished view of this extraordinary industry, given the breadth of social and environmental benefits it can also bring. However, understanding the economic potential of seaweed in Europe is an important first step towards quantifying the wider impacts that a vibrant commercial seaweed industry might bring. It is with such a holistic vision for the sector in mind that this chapter explores the potential market for seaweed products in Europe in 2030. It then considers how demand in the European market might be met, assessing the share to be supplied from local sources versus imports.

1.1 European demand in 2030

Approach

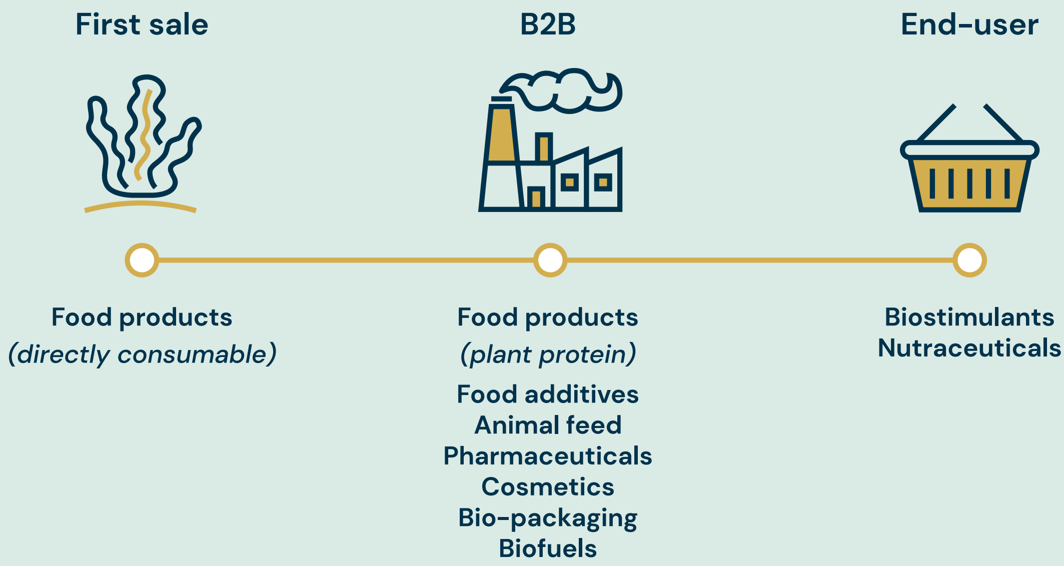
The total market potential in Europe was calculated as the sum of the market potential of eight different application segments: food products, food additives, animal feed, biostimulants, pharmaceuticals/nutraceuticals, cosmetics, bio-packaging and biofuels. Where appropriate, the modelling sized multiple sub-segments in order to calculate the potential for an overall segment (for example, the food additive segment was divided into three sub-segments: carrageenan, agar and alginate). The eight segments were selected as the most relevant given their current global market share, existing predictions for industry trends, and in line with input from industry experts. Ecosystem services provided by seaweed – both as it grows and through its applications as an end-use product – were also considered to be in scope. While the environmental impact of these services is sized later in this chapter, their economic value was not quantified as part of the modelling – this should though be the focus of further research, as it is likely to be significant.

These segments are not, however, exhaustive. The model excluded some nascent applications, including for instance textile fibres, laundry detergents and construction materials. While there is the potential for segments such as these to grow, the decision was taken to exclude them from the model due to the limited availability of both scientific data and commercial examples, which constrains efforts to quantify their potential growth.

Projections for the 2030 European seaweed market are necessarily uncertain. This is driven both by the inherent uncertainty of the future, and by data limitations relating to the market as it exists today. Accordingly, the model incorporated three ambition levels for key parameters, to reflect both ambiguity and potential in the market. The three ambition levels reflect a conservative, a moderate and a high-end case, the underlying assumptions of which are as follows:

- **Conservative ambition level:** minimal change to current demand trends, policies and cost trajectories.
- **Moderate ambition level:** isolated changes in demand trends, policies and cost trajectories that positively impact the context for the seaweed industry in Europe
- **High ambition level:** significant changes, including favourable policy environments, considerable economies of scale, further cost efficiencies from technological innovations, and strengthening advantageous consumer trends.

Figure 4 – Prices used to size the market for in scope segments



Valuations of the seaweed market will vary depending on what point of the value chain is in focus. In theory, there are three main points where prices can be ascertained: first sale (i.e. when a grower sells seaweed to a processor); intermediate business-to-business (B2B) sale (i.e. when a processor sells seaweed-derived ingredients to a transformer); and end-user sale (i.e. when a customer purchases a final product). The model used B2B prices where possible, as these were considered the most accurate reflection of seaweed demand (Figure 4). Firstly, this is because B2B prices capture value added to seaweed during processing, which first sale prices fail to do. Secondly, B2B prices avoid the complexity that arises from trying to deduce the share of an end-user product's value that is attributable to a seaweed-based 'ingredient'. This is salient as seaweed ingredients are often combined with non-seaweed materials before being brought to market (e.g. carrageenan extracted from seaweed by a processor that is then incorporated into a dairy product by a food producer). For segments where B2B data was not available, the model employed first sale or end-user prices. For the 'directly consumable' food product sub-segment, first sale prices were used as in many cases seaweed is only minimally changed by processors before sale to customers. By contrast, end-user prices were employed in the biostimulants segment and nutraceutical sub-segment as seaweed ingredients must be extracted by processors before a product can be brought to market, so end-user prices were considered a better proxy than B2B demand.

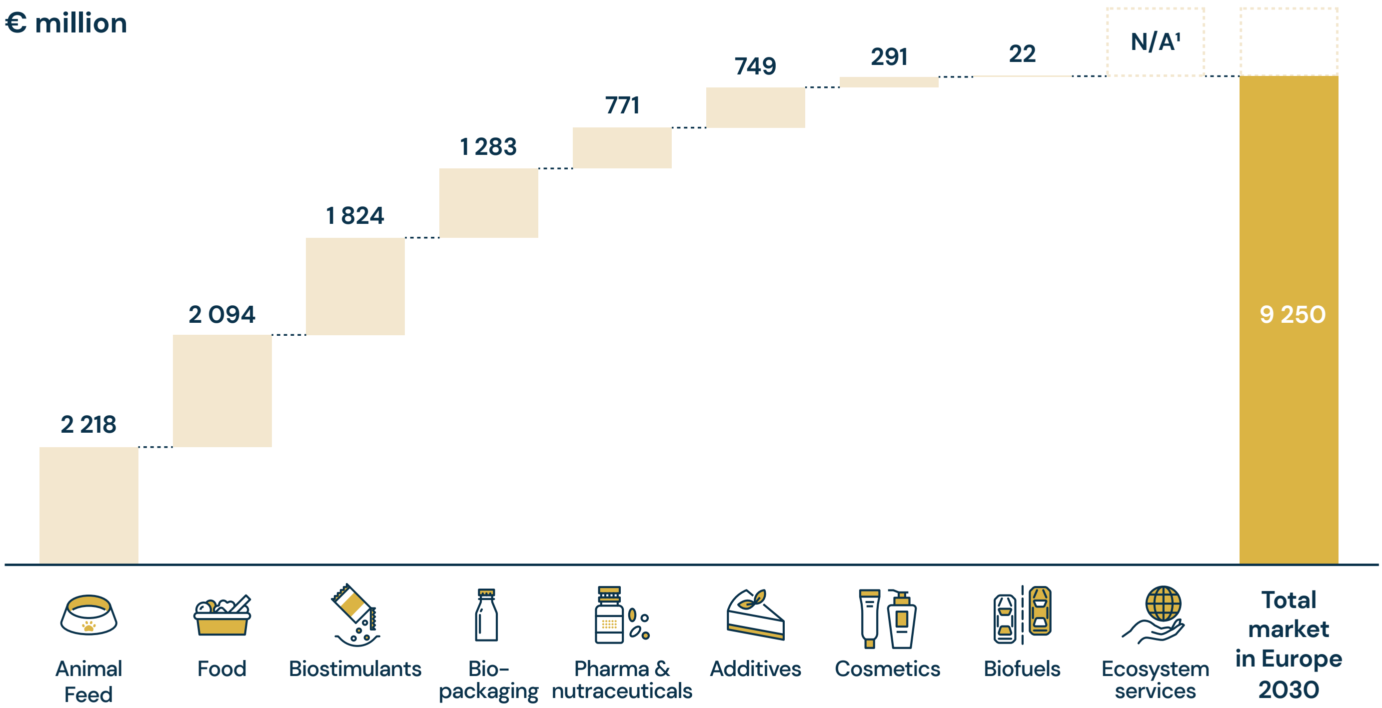
Out of scope

In line with the 80/20 principle outlined above, demand for European exports in 2030 was not sized as part of the modelling process. Expert interviews suggested that European supply in 2030 is likely to be predominantly absorbed by European demand. It is possible that some high-value niche products in which European producers have specific expertise may buck this trend, but this is likely to only contribute minimally to overall demand and supply figures.

Key takeaways

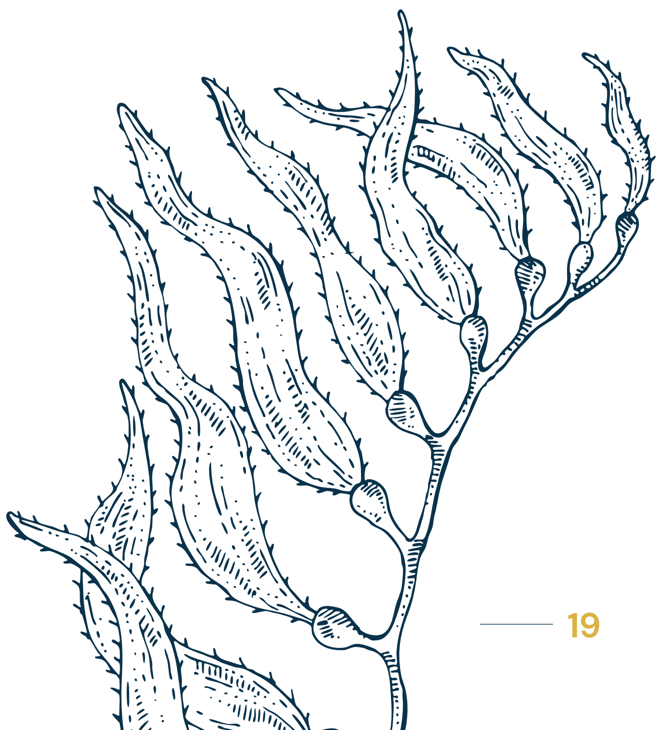
European demand for seaweed is projected to reach €3.0-9.3 billion in 2030 across all eight segments, with feed, food and biostimulants the largest (Figure 5). In the high ambition case, this would mean the seaweed market in Europe would be larger than EU aquaculture production in 2017, worth €5.1 billion, and within touching distance of the overall EU fisheries sector, valued at approximately €12-13 billion in the same year (Eurostat, 2019).

Figure 5 – European demand for seaweed products in 2030 (high ambition case)



1. As of today, not yet quantified, but important focus for future research.
Note: Values are for high ambition level - see Appendix for low and moderate ambition level outcomes. Total may differ due to rounding.

Animal feed: Of the 2030 European seaweed market, animal feed supplements are projected to constitute the largest segment, with a value of €540-2,220 million. This growth will be driven principally by the livestock feed additive sector, in particular for cattle, swine and poultry, on account of the many health and yield benefits that seaweed supplements offer. A further benefit from seaweed additives in feed is the potential for select species to reduce methane emissions in cattle. Should a European emission credit scheme be expanded to include enteric methane emissions from ruminants, this would open a revenue stream for farmers that would undoubtedly galvanise the sector and offer opportunities both for seaweed-based additives and for alternative plant-based additives, for which research is currently underway. Ultimately, such a policy could bring the high ambition value for the cattle feed additive market, representing €800 million, even closer.



Food: The European food segment is projected to reach between €700-2,100 million in 2030, driven by two sub-segments: the plant protein market and directly consumable seaweeds. While some seaweed is high in protein, such as Porphyra sp. which has a protein content of 47% of dry biomass (Barbier, et al., 2019), growth in this sub-segment is constrained by alternatives with a higher protein content and a more attractive cost structure, such as pea protein. The larger share of growth in the seaweed food market is likely to stem from the directly consumable sub-segment, which includes seaweed eaten raw or dried or incorporated whole into other food products. This more promising market is projected to be worth €600-1,800 million in 2030 and is expected to benefit significantly from continued strong growth in plant-based diets in Europe.

Biostimulants: In the most ambitious case, the 2030 European market for seaweed-based biostimulants (plant growth enhancers) could be worth €1,820 million. While this may seem optimistic, it could be within reach if hoped-for technological advances in processing come to pass – and, crucially, if EU policy is implemented and enforced to meaningfully raise the cost of conventional nitrogen fertilisers, including increasing the price of carbon. Should these conditions fail to materialise, however, seaweed-based biostimulants will be unable to compete in the bulk arable sector. As such, in the conservative and moderate ambition cases, biostimulants only have a market of €600-760 million, reflecting the fact that under other circumstances these will likely remain niche products predominantly for use in commercial fruit and vegetable and organic segments.

Although the projected size of the market in 2030 is expected to vary markedly between segments, all were judged economically viable in their own right, with the exception of biofuels – research suggests that the cost profile for conversion of seaweed to fuel will not fall sufficiently over the next 10 years to allow seaweed-derived biofuels to compete with alternatives. Also worth considering are ethical concerns over using (currently scarce) supplies of seaweed for fuel instead of for more urgent needs, such as the improvement of food security. Accordingly, the model does not anticipate a demand-led market for seaweed biofuel by 2030.

However, that is not to say there is no role for seaweed bioenergy. There is, in a cascading biorefinery process, a production approach under which multiple products are recovered from a single tonne of seaweed, with those of highest value prioritised. This process of fractionation results in biological leftovers, which can be further processed to create a fuel (Balina, Romagnoli & Blumberga, 2017). There is therefore potential to co-produce biofuels in conjunction with other applications in 2030. Under this approach, biofuels need not be profitable on a standalone basis, so long as they contribute to the overall yield and efficiency of the broader biorefinery structure. Modelled this way, if seaweed-based biofuels were co-produced with 15% of European supply, they could have a value of €6-22 million by 2030.

1.2 European demand captured by European supply in 2030

A multi-billion-euro seaweed market in 2030 is an attractive economic indicator, but for Europe to capture most of the additional social and environmental benefits of seaweed, a certain share of this demand needs to be supplied by seaweed grown along European coastlines.

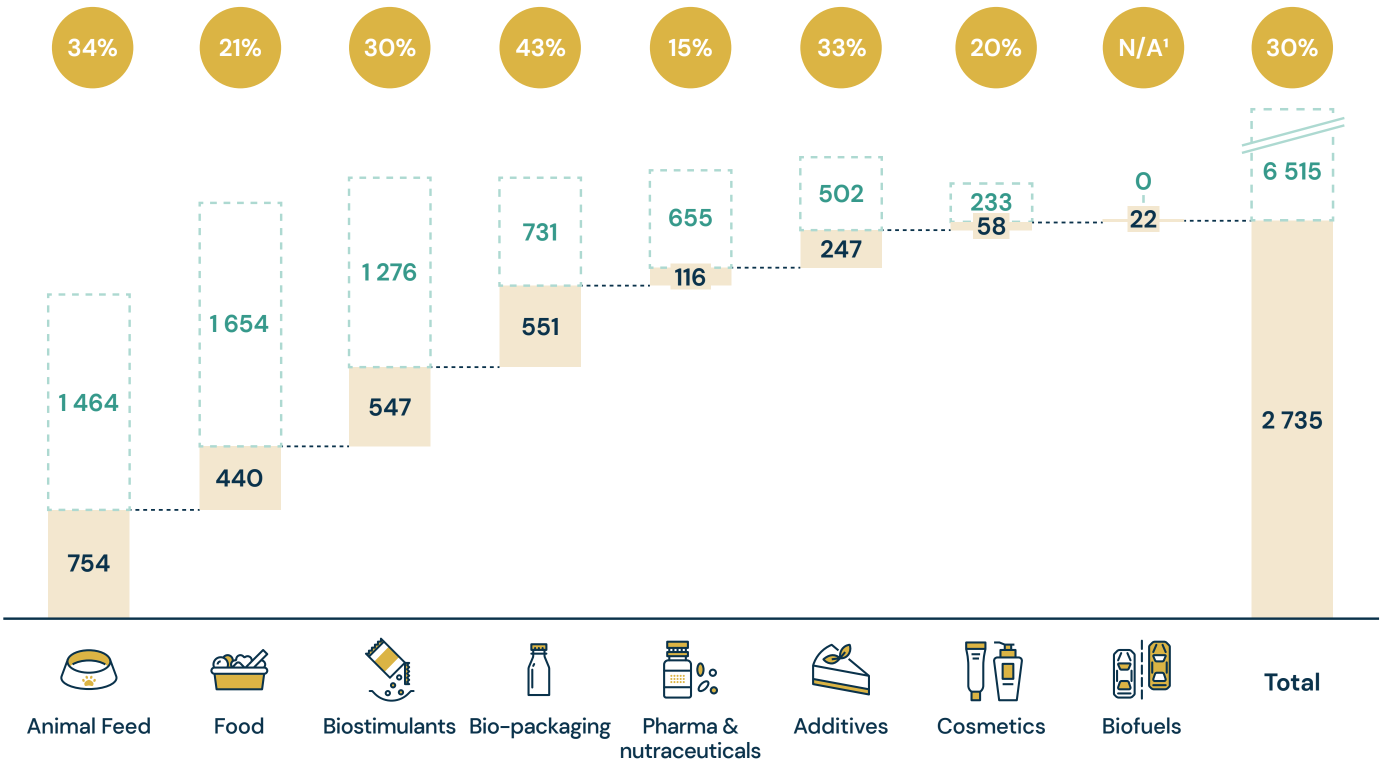
Approach

For each segment, industry experts were interviewed about key factors that would influence the ability of European producers to meet domestic demand. These factors included the relative strength of Asian producers, the importance of cost, quality and traceability within the segment, and the feasibility of cost-efficient European production at scale by 2030. Based on the performance of each segment against these factors, a percentage share of total European demand that could be captured by domestic producers was derived. This assessment was complemented by a consideration of the pre-requisites which would need to be satisfied for the specified share for European producers to be achievable.

Key takeaways

Of the total projected European market for seaweed in 2030, €0.9-2.7 billion could be captured by domestic producers, equivalent to 30% of total European demand (Figure 6). Achieving this would represent a pivot away from the current situation in which Asian producers dominate, both globally and in a European context, to one where European producers grow by leveraging core strengths including quality, traceability and innovation and take some of the domestic market share.

Figure 6 – European demand captured by European supply in 2030 (high ambition case)



The positive outlook for growth in European demand for seaweed over the next 10 years is good news for the European seaweed industry. It reflects a market in which European producers are well positioned and where consumer dynamics – in particular the importance of quality, traceability and locally-sourced, sustainable produce – are aligned to the direction of travel of existing players within the industry.

Notwithstanding this opportunity, imports will continue to benefit from lower labour costs, economies of scale, established and reliable logistics, and a lower regulatory burden. As a result, it is by no means a foregone conclusion that domestic producers will capture 30% of European demand. Whether or not they do will depend on two factors: segment-specific competitive dynamics, and the extent to which key cross-segment interventions to support European producers are realised (see Chapter 3).

The overall opportunity for European producers is founded on the opportunities and challenges within each individual market segment, across which there is significant variability (Figure 7). This is driven by divergence in competitive factors including the strength of incumbents in the rest of the world, and the relative importance of cost vs. quality, traceability and provenance. Bio-packaging is likely to see the highest share of the market accrue to European producers – up to 43% averaged across two sub-segments. This is largely due to the emerging market for 'non-transformed' naturally biodegradable products, including films, coatings and sachets, made from seaweed extracts. Domestic producers could capture as much as 70-80% of the non-transformed sub-segment, thanks to the advantage conferred by European suppliers' innovative technologies and focus on supply chain transparency.

Figure 7 – Opportunity for European producers to capture domestic demand by segment

Segment	Share of 2030 market captured by European producers	Rationale
Animal Feed	**34%** for livestock & aquafeed **38%** for pets	Potential for Europe to offset higher costs with innovation, automation. Europe also offers superior quality. However, cost is critical, so significant advances in processing technologies are required.
Food	**40%** for plant protein **15-20%** for directly consumable	Asia firmly established as incumbent, benefitting from low costs and fact that key edible species cannot be grown offshore in Europe. Potential to erode this advantage with focus on quality and local, transparent supply.
Biostimulants	**30%**	Relatively new market without clear incumbent. There is an opportunity for Europe in the bio-agriculture segment given focus on quality and traceability in addition to cost. Limited potential in bulk / arable market.
Bio-packaging	**70-80%** for non-transformed **10-20%** for transformed	Asia likely to dominate the 'transformed' market, as capacity already in place (for transformation of other sources of bioplastics). However, sustainable, transparent supply chain has potential to de-commoditise European produce in non-transformed sector (e.g. films, coatings, sachets).
Pharmaceuticals & nutraceuticals	**15%**	Europe's strength in quality and transparency could partly alleviate cost and reliable offtake advantages of Asian producers. However, cost remains key in nutraceutical market.
Additives	**33%**	Growing consumer focus on sustainable locally-sourced supply could allow producers to erode Asia's advantage as the established, low cost producer. However, this would call for significant cost efficiencies.
Cosmetics	**20%**	Europe's strength in quality and transparency could partly alleviate cost and reliable offtake advantages of Asian producers.
Biofuels	**N/A**	Seaweed-based biofuel will not be commercially viable by 2030. Biofuel production will therefore be driven by supply considerations (i.e. co-production of biofuels with other products to offset fixed costs).

Although competitive dynamics suggest that the European market presents a real opportunity for domestic producers, there is no guarantee they will be able to take it. Under current conditions, European companies face multiple structural constraints that, unless corrected, will hinder competition at scale with imports. The evolution of key consumer trends in the sustainability space also remains an unknown – their final trajectories will either help or seriously hinder the industry. Accordingly, for the potential 30% market share to be truly achievable for domestic producers, a number of system-level conditions must be in place by 2030; including for instance streamlined licensing processes to enable rapid expansion in farming capacity, regulatory reform to reduce the time needed to bring new products to market, and innovation in biorefinery processing to enable efficient co-production of multiple applications at low cost (see Chapter 3 for more details). Importantly, the ecosystem services potential of the European seaweed industry – both from an environmental and a valorised, economic perspective – will also depend on the extent to which European producers capture domestic demand.

2. A whole new regenerative farming industry to be developed to supply this European market

Supplying 30% of this significant European market in 2030 with domestically farmed seaweed will require a major boost in quantities produced. The modelling for the ambitious case scenario estimates a volume of up to 8.3 million tonnes of fresh seaweed, which would require up to 26,300 hectares of ocean surface area and over 1,000 hectares of onshore capacity to be devoted to seaweed farms in 2030.

Approach

Our model calculated the European capacity that would be required in 2030 based on the projected market for each segment and the share of the market assumed available to European producers to capture. Taken together, these revealed the addressable market for each segment. The value of each addressable market was converted into product tonnes, then dry seaweed tonnes, and finally fresh seaweed tonnes, using price data in the first instance and conversion ratios in the latter instances. The implied fresh tonnes for each segment were then summed to give the fresh seaweed supply that would be required, assuming each product was produced individually (i.e. assuming that just one type of seaweed application could be produced from a given tonne of fresh seaweed). However, multi-product seaweed biorefinery processes already enable ingredients for multiple applications to be co-produced from a single tonne of seaweed. Accordingly, the calculated fresh tonne supply was adjusted down to reflect the potential extent of co-production in 2030 and the efficiencies this could bring.

In order to calculate the ocean and land area required to meet European demand, the model segmented the final figure for fresh seaweed supply in tonnes between onshore and at-sea cultivation. Our expert interviews revealed a range of views on the likely contribution of onshore seaweed cultivation to the European supply in 2030, with estimates ranging from 1% to 10% or more. Based on this range, the model assumed that 5% of supply is grown on shore in Europe in 2030, and that 95% is grown at sea.

The fresh tonne supply projected to be grown at sea was converted into hectares at a rate of 30kg fresh weight per square metre (FW/m^2). Two main considerations were incorporated into the yield assumption, i.e. the volume of seaweed that can be produced for one metre of line or square metre of growing sheet. First, an average yield assumption of 30kg FW/m^2 represents a ~3x improvement in average yield over the next 10 years, which is considered feasible given advances in technology, breeding and seeding efficiency. Second, while yields of 30kg FW/m^2 have already been exceeded under best practice conditions, yields in this upper range are relevant to specific species only. A diverse, healthy seaweed industry should incorporate a range of seaweed species, including lower-yielding varieties, and the average yield reflects this diversity. Onshore cultivation is typically higher-yielding than offshore, given the greater potential to optimise growing conditions. Accordingly, a yield assumption of 40kg FW/m^2 for sizing the onshore land area required was adopted.

Key takeaways

The model's 2030 supply projections imply an expansion in annual production in Europe to 2.4-8.3 million tonnes of fresh seaweed. This would transform Europe's seaweed industry, not just in terms of scale, but also with respect to source. In 2015, 296,194 tonnes of seaweed were harvested in Europe, of which 99.5% was from wild stocks and just 0.5% was cultivated (FAO 2018). However, while wild harvesting may well continue in 2030, its volumes are reaching the safe ecological ceiling.[3] Growth in the European seaweed industry will therefore need to emerge rapidly from the aquaculture sector. There is no doubt that this is a major challenge. However, the recent history of Asian seaweed supply would suggest that it is eminently possible: in just 10 years between 2005 and 2015, annual production in Asia grew by over 16 million fresh tonnes (FAO, 2020).

Assuming 95% of the tonnage is grown at sea, Europe will need to expand its supply to 2.3-7.9 million fresh tonnes, implying a cultivation capacity in the region of 7,700-26,300 hectares – an area equivalent to between 1 and 3% of Belgium. Put another way, cultivation on this level would occupy just 0.02-0.06% of Scotland's Exclusive Economic Zone (the sea area within 200 nautical miles of a coastal nation over which it has a right to marine resources (Scottish Environmental Protection Agency, 2016)). Creating an industry on this scale is therefore eminently possible without the need to occupy an excessively large surface area of the ocean. Moreover, given that cultivation capacity will not be confined to a single country, but rather distributed across many, the impact on available coastal areas will be further dispersed. Achieving such scale is nonetheless a huge step up from the current seaweed landscape and speaks to the need for fundamental changes if the industry is to grow.

3 For wild harvesting to be part of a sustainable European industry in 2030, the process must in any event be carefully managed in order to protect ecosystem health. This calls for the avoidance of harmful practices, including the over-exploitation of seaweed resources, harvesting that depletes specific species, and excessive removal of holdfast material (similar to roots) (Monagail, Cornish, Morrison, Araújo & Critchley, 2017).

If 5% of the tonnage is grown on land, onshore cultivation could supply 0.1-0.4 million fresh tonnes, which would require 300-1,000 hectares of seaweed farming capacity on land. In reality this figure could be higher or lower, depending largely on the extent to which offshore licensing processes are optimised in the coming decade. Land availability constraints are also likely to impact the development of onshore capacity. However, these constraints can be loosened through innovative approaches, such as targeting abandoned lands including former industrial sites for the development of onshore farms.

While growth in cultivation capacity is an obvious necessity to realise the potential of the European seaweed industry, it is equally important that capacity is increased along the entire value chain – particularly in infrastructure, including drying and freezing, which should be available close to farms. This infrastructure is crucial to ensure that seaweed can be rapidly preserved after harvest and that seasonal variations in yield can be smoothed. Processing infrastructure more broadly is also key to enabling a balanced growth trajectory that avoids bottlenecks and an uneven distribution of power and value that could undermine ambitions for a just and equitable industry (see chapters 2 and 3 for further considerations on how to develop this supply chain).

Part of what makes seaweed so extraordinary is the sheer range of species, and the different properties that they offer. A further consideration for the industry as it scales will therefore be the relative quantities in which different species are produced, and at which locations. The ultimate distribution will be driven by a number of factors, including the individual suitability of specific areas in terms of temperature and nutrient content for certain species, whether a species is non-native or native, whether it can be grown at sea or on land, and the needs of different industry sectors. With these conditions in mind, industry experts have suggested that key seaweeds grown in Europe in 2030 could include for instance sea lettuce (Ulva lactuca) for human consumption, sugar kelp (Saccharina latissima) for use in food products and animal feed, dabberlocks (Alaria esculenta) and dulse (Palmaria palmata) for the food and cosmetics sectors, Asparagopsis taxiformis for cattle feed additives with methane-reducing properties, and oarweed (Laminaria digitata) for the production of alginate for use in the food additives and bio-packaging segments (Figure 8).

Figure 8 – Examples of key species grown in Europe in 2030

Sea Lettuce
Ulva lactuca

Dabberlocks
Alaria esculenta

Sugar Kelp
Saccharina latissima

Oarweed
Laminaria digitata

Asparagopsis taxiformis

Dulse
Palmaria palmata

Source: Atlantic Gozo, 2020; Flickr, 2020; Liberal Dictionary, 2020; Nature Picture Library, 2020; The Seaweed Site, 2020)

3. A significant job creation opportunity

A thriving European seaweed industry will create many new jobs, especially if a 30% share of the market is produced domestically. In the high ambition case, the seaweed sector could create up to 85,000 jobs on a full-time employee (FTE) equivalent basis in Europe by 2030.

Given that parts of the seaweed value chain rely on seasonal workers employed on a temporary basis, in practical terms this figure could actually represent employment of some kind for around 115,000 people. These employment opportunities will not be limited directly to seaweed aquaculture and processing but will also arise in related industries and in the wider economy, creating opportunities for workers with a range of different skill-sets.

Approach

The model calculated direct, indirect and induced job potential in the European seaweed industry in 2030 based on supply and demand projections.

Direct jobs in Europe were calculated for both domestic supply and for imports. For the sizing of domestic supply on an FTE equivalent basis, the model assumed that the end product is both grown and finished within Europe. Employees are modelled for every step in the value chain, with an assumed total of 27 FTEs per 10,000 FW tonnes based on expert interviews (Figure 9).

For the remainder of European demand, which will be met by imports, it is assumed that only a sub-set of the value chain takes place in Europe, and that FTEs are correspondingly lower. Imports are split into products that are both grown and finished outside Europe and into products which are grown outside Europe, but processed and finished within Europe – these account for 1 and 11.5 FTEs per 10,000 FW tonnes respectively (Figure 9).

Figure 9 – Distribution of direct FTEs along the European seaweed value chain in 2030

Direct jobs (FTE) / 10k fresh weight tonnes (fw t)

	Hatchery	Farming and Harvesting	Logistics	Processing	Marketing & Sales	Distribution	Total direct jobs (FTE) / 10k fw t
Grown and finished in Europe	5	3	6	8	3	2	**27**
Grown elsewhere finished in Europe			3	4	3	2	**12**
Grown and finished elsewhere					0.5	0.5	**1**

Indirect jobs arising from changes in employment in the seaweed supply and distribution chains were calculated using a multiplier of 1.75, which is in the range of 1.5-2 for European marine fisheries and aquaculture industries (Capgemini Consulting, Executive Agency for Small and Medium-sized Enterprises (European Commission), Ramboll, 2016). This means that every FTE active in the seaweed industry is expected to generate 0.75 FTEs in ancillary industries, including servicing of equipment and vessels, supplies for operations, and research, development and investment services.

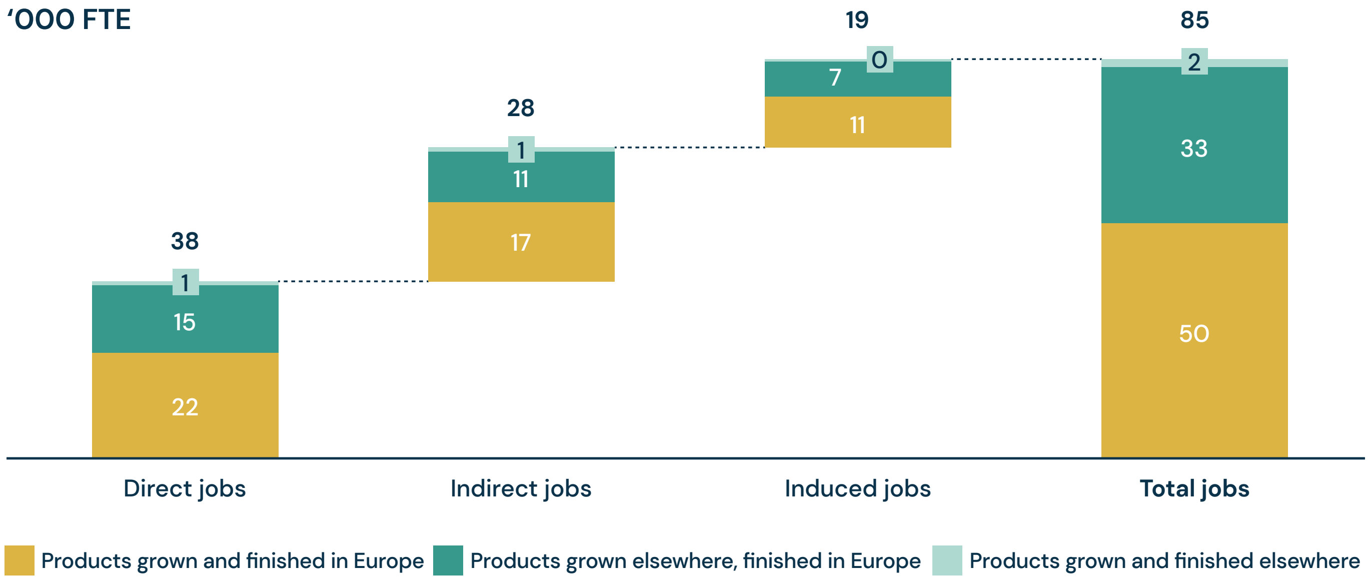
Induced jobs created by increased demand in the economy from additional income were calculated from an indirect and induced multiplier of 2.25, which lies in the range for fisheries and aquaculture industries in the UK and was used as a proxy for the European industry more widely (Strathclyde University, 2002). Given the indirect multiplier used in the analysis, an indirect and induced multiplier of 2.25 indicates that for every FTE employed directly by the seaweed industry, a further 0.5 FTEs will be generated in the wider economy by the resulting additional spending.

In addition to FTE equivalent jobs created by the industry, the model determined the potential number of people directly employed by the sector in 2030, to reflect the fact that multiple seasonal workers can be accounted into a single FTE in some stages of the value chain. The model assumed that harvesting and logistics are seasonal activities, and that they typically employ four temporary workers each working for three months of the year for every stated FTE.

Key takeaways

The seaweed industry is projected to create 26,000 to 85,000 FTE equivalent jobs in Europe by 2030 (Figure 10). Of these, 12,000 to 38,000 will be direct jobs created either by European domestic supply or by imports. When full and temporary roles are considered individually, the direct employment potential of the industry rises to 21,000 to 68,000 jobs. The upshot is that by 2030, the seaweed sector could create as many or more employment opportunities than the European aquaculture sector offered in 2017, when full and part-time jobs together represented 44,000 FTEs (European Commisison, 2019a).

Figure 10 – Potential jobs created in Europe by the seaweed industry in 2030



Note: Values are for high ambition level - see Appendix for low and moderate ambition level outcomes. Totals may differ due to rounding.

The seaweed industry's potential for job creation has never been so important or attractive as it is today. The global economy sits under a shadow of uncertainty over how – and how quickly – the economy will recover in a post-COVID world. In this context, a new, vibrant industry creating secure jobs in Europe is highly significant. In addition, the seaweed industry offers the opportunity for reskilling or upskilling those who have become unemployed, and for young people without prior experience who are likely to struggle most in the labour market in the coming decade. Finally, it represents a special opportunity for coastal communities, where jobs in hatcheries, cultivation, harvesting and some processing will likely be concentrated. This employment boom has the potential to diversify livelihoods and revitalise lower income coastal areas.

With the right level of ambition, the European seaweed sector can aspire to not only create employment opportunities, but actually foster good jobs, that give back to employees and their local communities. This aspiration might manifest through the creation of jobs for young people struggling in the job market, the ongoing upskilling of employees, and investments in the local community. If the industry is to be truly socially sustainable, however, it should also have a considered awareness of the competing uses for coastal waters and balance its own needs with those of local communities.

Strengthening the supply chain for the European seaweed industry could in itself deliver further social benefits. Today, the majority of seaweed in Europe is imported, leaving the supply chain vulnerable to unexpected shocks – the COVID crisis has demonstrated how significant this can be for many different industries. As the domestic sector grows however, distances within the seaweed value chain will shorten and supply sources will diversify, making the supply chain more resilient. This trend will better protect downstream players in the seaweed value chain and ancillary industries from volatility in the global seaweed market and could therefore enhance job security.

4. Considerable benefits to the environment in 2030

Expansion of the seaweed industry in Europe offers many varied environmental benefits. These range from carbon sequestration and offsetting emissions, to eutrophication mitigation, to a host of other ecosystem services. With further research to quantify some of the less-well-understood environmental impacts of the sector, and ongoing monitoring to manage risk, seaweed aquaculture undoubtedly has the potential to be an overwhelming force for good in efforts to tackle the climate and ecological emergencies.

4.1 Climate mitigation potential

As anthropogenic greenhouse gas emissions continue to climb, the world is moving ever closer to 2°C of global warming above pre-industrial levels, which would be accompanied by catastrophic climate change impacts. Remaining within the safer guardrail of 1.5°C of warming calls for rapid and sweeping mitigation efforts in order to reach net-zero CO_2 emissions by 2050 (IPCC, 2018). Innovative ocean-based solutions can play a central role, with seaweed touted by some as a potential component of these mitigation initiatives (Krause-Jensen & Duarte, 2016; Ortega, et al., 2019).

Approach

There are two main pathways through which commercial seaweed aquaculture can positively impact greenhouse gas emissions: natural sequestration and end-use products (Gaines, et al., 2019). To reflect uncertainty both in terms of the size of the European seaweed industry in 2030 and the net emission-saving potential of seaweed on a per tonne basis, an ambitious upper bound and conservative lower bound for the emissions impact of the sector were calculated.

To ascertain the natural sequestration potential of the industry, upper and lower bounds for sequestration per dry tonne of seaweed were determined based on variations in two parameters. The first is the rate of biomass lost during growth as a percentage of total seaweed biomass. The second is the share of carbon in the lost biomass that sinks in the deep sea and is sequestered (i.e. removed from the atmosphere for long periods). These upper and lower bounds for sequestration were applied to the projected European supply in 2030 to calculate gross emissions, before subtracting cradle-to-harvest life cycle emissions to derive net emissions.

Three segments were considered to demonstrate the potential for avoiding emissions with seaweed end products: animal feed, bio-packaging and biofuel. This selection reflects two considerations: mitigation potential and data availability. Other segments which are also considered to have significant mitigation potential – in particular biostimulants and to a lesser extent the food product sector – were excluded due to limited data.

To size the mitigation impact of the animal feed, bio-packaging and biofuel segments, the upper and lower bounds for net life cycle emissions for each product per dry tonne of seaweed were determined. These values include both the offsetting potential in CO_2 equivalent tonnes and the end-to-end carbon emissions involved in production. The difference between the upper and lower bounds was driven by ranges in the carbon intensity of production (for all three segments), the potential efficacy in terms of abating emissions (for the animal feed segment), and the carbon intensity of alternatives (for the biofuel and bio-packaging segments). The net life cycle emissions per dry tonne were then applied to the projected European supply of seaweed for each segment in 2030, to give a range for total avoided emissions.

Carbon dioxide removal

The mitigation potential of deep ocean sinking, where large quantities of seaweed are grown and deliberately sunk to the deep ocean to be sequestered, was not sized in this report. The decision to place sinking for carbon dioxide removal purposes (CDR) out of scope was driven by two main considerations. Firstly, sinking represents a pure mitigation strategy that would most likely be pursued discretely from commercial seaweed aquaculture – which is the focus of this report. Secondly, sinking remains an as yet untested concept; at this time, the technology is unproven, its implications on deep-sea ecosystems uncertain, and economically viable pathways reliant on grants, subsidies or a more favourable carbon market. However, that is not to say that CDR should be discounted. Technological and scientific progress will undoubtedly take place in the coming decade, and the business case for sinking seaweed could become viable if the carbon price were to rise above a certain threshold, and if the CO_2 sequestered was quantified, certified and tradable through seaweed-specific carbon credit standards. These conditions could enable significant sequestration from seaweed aquaculture. A cultivation area of 1000 km^2 in the Norwegian Sea – equivalent to just 1% of the sea area within the Norwegian maritime baseline – could for example generate a potential biomass yield of 20 million FW tonnes per year (Broch, et al., 2019). This could remove ~4 million tonnes of CO_2 each year, of which a significant proportion could ultimately be sequestered, depending on sequestration efficiency and footprint involved.

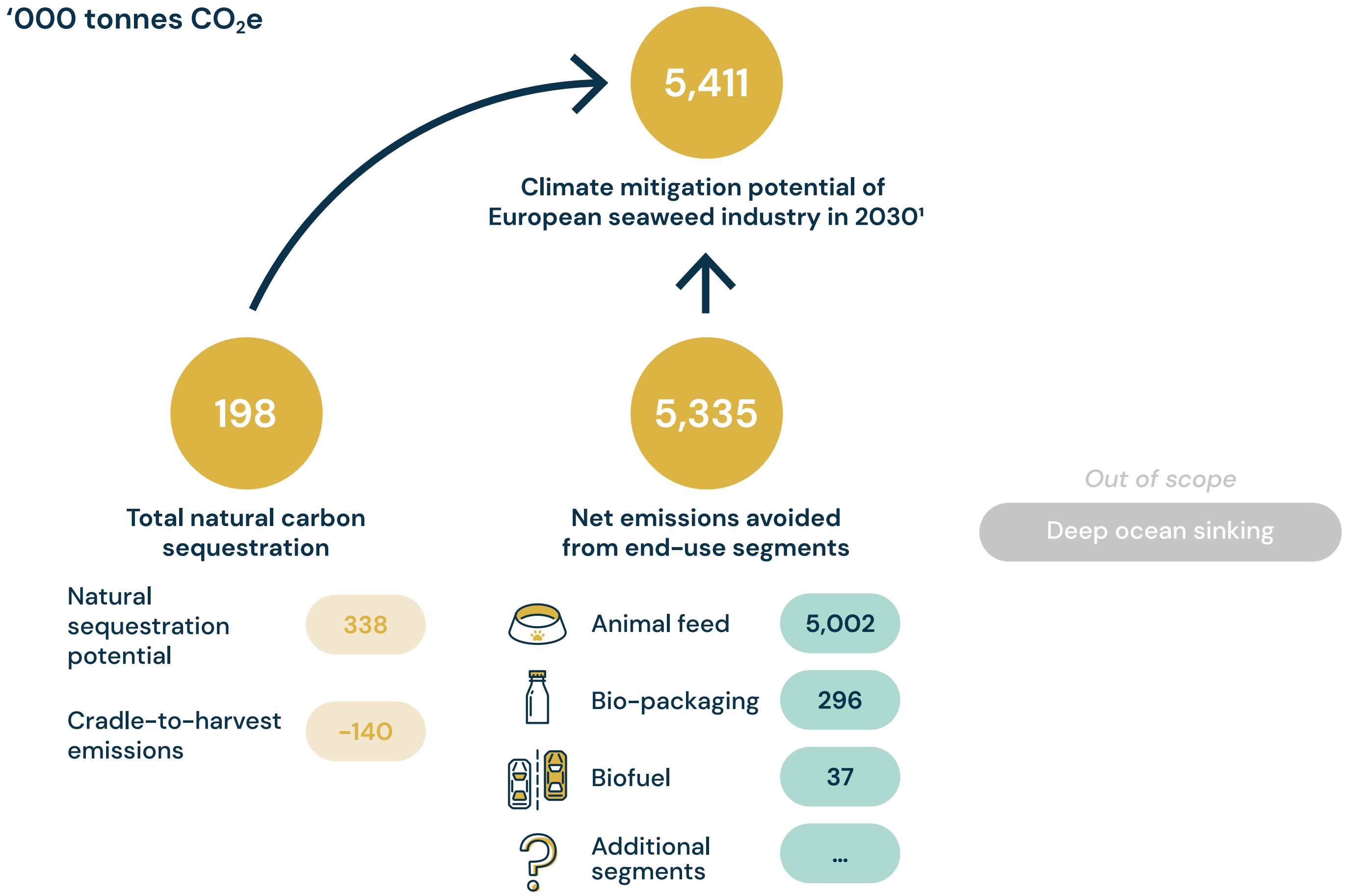
Similarly, restoration of wild forests of seaweed (declining at an alarming rate) could have a significant positive impact on GHG mitigation but was not addressed in this report as the focus was on commercial use of seaweed.

Key takeaways

In the high ambition case, the greenhouse gas mitigation potential from the European seaweed sector could exceed 5.4 million CO_2e tonnes in 2030, equivalent to offsetting carbon emissions from 773,000 Europeans (Figure 11).

Research suggests that seaweed could contribute towards alleviating the environmental impacts of climate change by absorbing carbon (Krause-Jensen & Duarte, 2016; Ortega, et al., 2019). However, in a 2030 commercial aquaculture setting, natural sequestration of carbon by seaweed will not contribute significantly to carbon offsetting.

Figure 11 – Potential for greenhouse gas emission savings in 2030 (high ambition case)



1. Emissions avoided from end-use segments includes natural sequestration potential. Total potential for the industry is therefore adjusted down to account for this overlap.
Note: Values are for high ambition level - see Appendix for low and moderate ambition level outcomes. Sub-totals may differ due to rounding.

Mitigation potential is limited first by the fact that the carbon within harvested seaweed will not be sequestered, as it is released in the processes of producing and consuming end-use products. Moreover, even carbon within the biomass that is lost before harvest will not be fully sequestered, as only the carbon that is exported to the deep ocean or sequestered as particulate organic carbon will be stored for long periods of time (Gaines, et al., 2019). Consequently, end-use applications of seaweed, in particular cattle feed additives, are likely to have a far greater mitigation impact.

European seaweed aquaculture has the potential to naturally sequester up to 338,000 tonnes of CO_2 in 2030. Given that European annual per capita CO_2 emissions are approximately 7 tonnes (Eurostat, 2020), this is equivalent to offsetting the carbon footprint of more than 48,000 people, or around 1% of the population of Ireland. However, if cradle-to-harvest emissions from the projected seaweed stock are also taken into account, the net sequestration potential in the high ambition case is 198,000 tonnes of CO_2 (Figure 11), equivalent to offsetting the carbon emissions of 28,000

> “The next ten years will determine the future of our oceans. Regenerative seaweed farming can be a powerful means to restore abundance to our oceans and mitigate the impact of climate change.”
>
> Alexandra Cousteau, Founder of Oceans 2050

Europeans, or just 0.6% of the population of Ireland. Based on the carbon intensity of seaweed production today, at the most conservative ambition level its net sequestration potential in 2030 could be negligible, or even negative. However, with continued progress in scaling the industry, technological advances, and an increase in carbon-locking farming practices (such as designating fallow areas that are not harvested or are harvested less frequently) – perhaps with the help of subsidies – natural sequestration from seaweed aquaculture can be still be part of a portfolio of climate mitigation solutions in the future.

The most significant mitigation role for seaweed aquaculture in Europe is likely to come from its end-use applications. Seaweed supplements for cattle, for example, can reduce enteric methane emissions by up to 98% (Kinley, et al., 2020). This means the animal feed segment could potentially reduce emissions of 5,002,000 CO_2 equivalent tonnes in 2030 (Figure 11), which is comparable to offsetting the annual carbon emissions of 715,000 Europeans, or 15% of the population of Ireland. Whether it achieves these heights depends on demand and how successfully European producers can meet it, as well as on the supplements' true mitigation potential – there is not yet clear consensus on the precise extent of methane reduction when applied in commercial rather than research contexts. Consequently, further research and real-life tests will be needed.

Substituting traditional, fossil-fuel derived plastic for seaweed-based bio-packaging could also save greenhouse gas emissions totalling up to 296,000 tonnes CO_2e annually (Figure 11) – equivalent to the carbon emissions from 42,000 Europeans. Both the transformed and non-transformed sub-segments potentially contribute to this, constituting 89,000 and 207,000 tonnes CO_2e respectively. However, achieving these high-ambition carbon savings in the transformed sector is highly contingent on the availability and use of optimal end-of-life technologies for treating compostable plastic waste (COWI A/S and Utrecht University, 2018), or, in the longer term, on the potential for carbon capture storage for waste incineration plants.

Although seaweed biofuels will not be commercially viable at scale by 2030, they may be less carbon-intensive than alternatives, and accordingly do have the potential to support a green energy transition over a longer time horizon. Relative to corn-based bioethanol, seaweed bioethanol could offer a net emissions saving of as much as 227kg CO_2/dry weight tonne (DW T) if savings gained by avoiding land-use change are considered (Gaines, et al., 2019). Alternatively, if seaweed bioethanol is instead used to replace petrol, this net emissions saving rises to up to 239kg CO_2/DW T. If the limited volume of biofuels projected for the European industry in 2030 were used exclusively to replace petrol, that would imply a total offset of up to 37,000 tonnes of CO_2 (Figure 11) – equivalent to the annual carbon emissions of 5,310 Europeans. However, at present there is still uncertainty surrounding the net emissions impacts of seaweed bioenergy, so further research will be needed as and when biofuel technology matures.

It should be noted that other end-use segments for seaweed, particularly biostimulants and the food sector, are also expected to hold significant mitigation potential. In the food sector, for instance, depending on what land-based produce seaweed displaces, carbon benefits could be gained from avoided deforestation. However, further research is still needed to quantify these impacts, so they have not been considered in this report.

4.2 Nitrogen and phosphorous removal potential

Nitrogen and phosphorous are among the primary nutrients in the commercial fertilisers applied in intensive agriculture systems. When applied excessively, the unused nutrients can run off into coastal waters. Surplus food and waste products from coastal finfish and shrimp aquaculture can also contribute to marine nitrogen and phosphorous loads. In overabundance, however, these nutrients and lead to eutrophication, increasing the probability of harmful algal blooms and the risk of dead zones (FAO, 1992; Xiao, Agusti, Lin & Li, 2017). Given that seaweed not only grows without the use of fertiliser or other inputs, but actually assimilates nitrogen and phosphorous, seaweed aquaculture has a clear role to play in mitigating coastal eutrophication. A further advantage of this process is that if seaweed is converted into end products, it effectively enables more efficient use of the essential macrominerals on which plants depend. This benefit is particularly salient in the case of phosphorous as it is a finite resource, the stocks of which could be depleted to dangerously low levels in the future due to its overexploitation for use in fertilisers. Developing seaweed into end-use products therefore can support greater resource efficiency and help create a regenerative circular economy for phosphorous use.

Approach

The same overarching approach was taken to determine the potential for removal of both nitrogen and phosphorous from European waters. Firstly, the average nutrient content as a percentage of dry biomass was determined for both nitrogen and phosphorous. The percentages were then applied to the projected scenarios for European seaweed supply in 2030 to give a range of potential tonnes of each nutrient that could be removed from the ocean by the seaweed industry.

Key takeaways

In 2030, the European seaweed industry could remove between 6,000-20,000 tonnes of nitrogen and between 600-2,000 tonnes of phosphorous from coastal waters every year. Doing so would significantly improve marine water quality, particularly with respect to phosphorous. Nutrient removal at this scale would be equivalent to removing 2-6% and 4-13% of the estimated input of anthropogenic nitrogen and phosphorous respectively to the Baltic Sea in 2014 (Helcom, 2018).

4.3 Other ecosystem services and sustainability impacts

Beyond its climate change and eutrophication mitigation benefits, seaweed provides a number of further ecosystem services, both in terms of direct benefits for marine ecosystems and wider second order benefits. These can help the industry to lead by example in efforts to build a truly sustainable European economy. The benefits are challenging to quantify, however, and as such have been assessed qualitatively.

Considering first the direct impacts of seaweed aquaculture, the sector brings multiple benefits for water quality, both within marine ecosystems and for the coastal communities who depend on their health. Seaweed supplies oxygen to and increases the pH of the water it grows in, and so reduces both the hypoxia that occurs with eutrophication, and ocean acidification – a problem that is becoming ever more acute as increasing quantities of CO_2 are absorbed by the ocean (Duarte, Wu, Xiao, Bruhn & Krause-Jensen, 2017). Other benefits include the removal of heavy metals and suspended solids (for instance Chlorella vulgaris can remove up to 90% of heavy metals from wastewater). Together with the habitat offered by seaweed aquaculture, these water quality improvements can support biodiversity. The positive impacts are likely to be felt directly by marine life – as seaweed farms can serve as nursery grounds for fish and shellfish species – and as overspill benefits for seabirds, for which seaweed aquaculture can offer resting points and feeding grounds. Furthermore, if seaweed farms limit other environmentally disruptive human activities from taking place in a marine environment they can effectively perform the same function as Marine Protected Areas (MPAs), which is likely to benefit benthic habitats and organisms (i.e. those found on the seabed). Importantly, offshore seaweed farms can also support climate change adaptation for coastal communities, as their presence in the water can attenuate wave energy, thereby alleviating coastal erosion (Duarte, Wu, Xiao, Bruhn & Krause-Jensen, 2017).

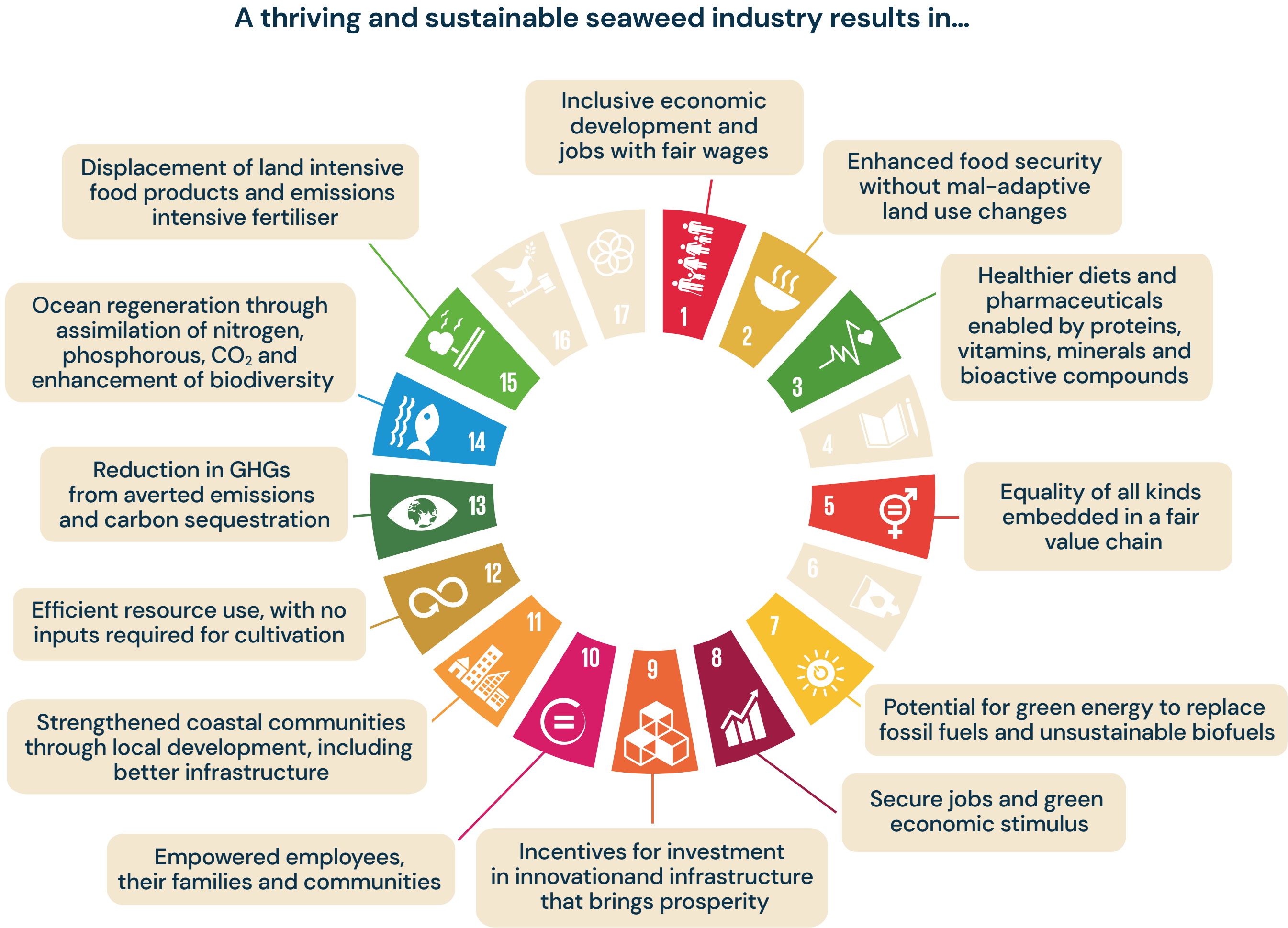
In terms of second-order or indirect benefits, the seaweed industry has wider impacts, including for terrestrial ecosystems. For instance, if seaweed food products displace land-based produce, this can spare land that would otherwise have been converted for agriculture, with a concomitant benefit for the species whose survival relies on those areas (World Bank Group, 2016). A similar benefit also accrues to fresh water supplies, as products derived from seaweed aquaculture, which requires no fresh water, can replace outputs of water-intensive agriculture – a benefit that will become more acute moving forwards as climate change intensifies water scarcity. Finally, if non-biodegradable plastics, or those that are biodegradable only under conditions of industrial composting, are replaced with non-transformed seaweed bio-packaging that is truly bio-benign, seaweed can help build a circular economy for plastic and alleviate the threat ocean plastic presents both to wildlife and affected coastal communities (Lau, et al., 2020).

However, it should be noted that expansion of the seaweed industry in Europe may bring risks, particularly for marine ecosystems, if it is not managed carefully. While small-scale aquaculture poses minimal risks, larger farms bring with them serious environmental management considerations. On large scales, human interventions – whether the reduction of genetic diversity in local seaweed, the introduction of non-native species, or the noise, artificial material and infrastructure associated with cultivation – all pose a risk to the wellbeing of native marine plant and animal life (Campbell, et al., 2019). The carrying capacity for seaweed aquaculture of European coastal waters is also currently unknown and should be assessed as the sector develops. It is therefore of paramount importance that expansion of the industry and the concomitant growth in farm scale is carefully managed and supported with ongoing monitoring and further research.

Over and above discrete ecosystem services, seaweed aquaculture offers a real opportunity to leverage nature-based solutions in tackling the climate and ecological crises. As a poster case for regenerative approaches, it could send a clear message to the wider agricultural and food industries on the need to embed conservation and rehabilitation as core principles within economic development. Furthermore, its climate change mitigation contributions can support the EU Green Deal's target of a 55% reduction in greenhouse gas emissions by 2030 compared with 1990 levels (European Commission, 2019b).

Finally, if deployed at scale, the seaweed industry could be an accelerator for sustainable development in Europe. This is abundantly apparent when the UN's Sustainable Development Goals (SDGs) are considered: the seaweed industry supports not just a handful, but almost the entire SDG agenda (Figure 12). These synergies are a clear indication that the seaweed industry can promote prosperity while safeguarding the planet.

Figure 12 – The seaweed sector in Europe supports the overwhelming majority of the UN's Sustainable Development Goals



In light of the strong economic potential, social benefits and green credentials of seaweed highlighted in this chapter, it is clear that growth of this industry represents a hugely exciting opportunity for Europe, as well as for stakeholders wanting to contribute towards building a just and sustainable future.

CHAPTER II

Defining sustainable growth: a vision for the European seaweed industry

With such an extensive potential for growth there are also significant risks. The development of the European seaweed industry must therefore be carefully managed.

Given the nature of the economic system we live in, it would only be natural for stakeholders wanting to unlock this opportunity to focus primarily on maximising individual profit at every step of the way – as has been seen to be the case in many other industries.

Over recent years it has, however, become increasingly apparent that setting economic priorities in isolation from environmental realities is a deeply flawed approach, as it comes at the expense of human and planetary health and wellbeing. General disregard for long-term sustainability has already caused significant damage to our planet. According to the United Nations, 1 million species are in danger of extinction. Land degradation in turn has caused a productivity decline for 23% of global terrestrial land (IPBES, 2019). If we continue unsustainable consumption and industrial and agricultural practices, we are unlikely to meet even the 2°C goal of the Paris Agreement (Raftery, Zimmer, Frierson, Startz & Liu, 2017). Inequality is also on the rise throughout the world, with a growing divergence of income (Picketty, 2014). In 2019, 1% of the world's adult population owned 44% of global wealth, while more than half the global population owned less than US$10,000 (~€8,900)[4] individually (Credit Suisse, 2019).

The limitations of our globalised economic system, made up of complex interdependent supply chains spanning several continents and relying heavily on imports/exports, have also been painfully highlighted by the recent COVID-19 crisis. As many industries struggled to adapt to the extraordinary circumstances, the world ground almost to a halt. This threatened livelihoods and food security, in particular among the most vulnerable parts of society. A recent Oxfam report has suggested that the resulting economic crisis could push more than half a billion people into poverty (Oxfam, 2020).

In light of this inability to withstand unexpected shocks and a growing concern that our current system is increasingly unfit to deal with some of the most pressing issues the world faces, there is a clear need for a complete reset. A key component of such a reset must be the creation of a new normal" which places long-term social and environmental sustainability at the heart of the global economic system, by promoting freedom, dignity, equality, human rights and justice alongside economic prosperity, and recognising nature as an indispensable partner to be treated with respect and care. A seaweed industry which does not adequately reflect this need risks perpetuating a system which in the long run will simply not remain tenable.

In order to move towards a new system, many industries will need to undergo the difficult process of questioning existing business models and adapting or even changing established structures. Seaweed stakeholders in Europe, in contrast, have an almost blank slate to define and build their industry from scratch. Many of the structures and conditions integral to longstanding and well-functioning industries are still lacking. A scaled and integrated supply chain is yet to be created. In parallel, supply and demand for seaweed must be stimulated, supported inter alia by targeted regulatory policies adapted to the particularities of seaweed. Meanwhile science must provide more detailed information about the benefits and risks associated with seaweed, which will help determine specific application segments to develop further and ensure sustainable production processes. To enable all this, investments financing innovation and infrastructure must be mobilised.

In short, there is a unique opportunity – indeed a responsibility – to create a seaweed industry which includes people and planet as part of the growth story from the outset. In doing so, the sector could become a paradigm for a new type of sustainable industry, the type which must play a central role in our "new normal" as we adapt for the future.

In order to ensure such an ambition, however, does not remain just that – a mere ambition, neglected as the industry grows larger and the world reverts back to a calmer state – it is essential to put guiding principles into place and embed these deeply within industry structures as they begin to develop.

4. At an average annual exchange rate of €0.8931 to US$1 (www.exchangerates.org.uk/USD-EUR-spot-exchange-rates-history-2019.html).

Travelling to 2030: a thriving European seaweed industry

While it is of course impossible to predict the future, looking ahead to 2030 allows us to gain a better understanding of how the role of seaweed could change. This vision exercise also helps highlight the core principles needed to succeed in creating an industry which is underpinned by an emphasis on long-term sustainability.

Let us imagine seaweed is no longer a "hidden champion" in 2030. The seaweed market in Europe is now worth €9.3 billion, supplied by 27,300 ha of innovative small and large-scale seaweed farms along the coastlines operating with sustainable practices. The industry has contributed to a successful green recovery and leads by example in showing that sustainability and economic success can be part of the same story. The industry is sustainable, empowering and innovative, a textbook case of what can be achieved when stakeholders unite around a common goal and put people and planet on an equal footing with economic prosperity.

As a result of this growth, seaweed is no longer a niche product. Its environmental and health benefits are recognised by consumers across Europe. Seaweed-based food is easy to find in supermarkets and many of the products are wrapped in nature-friendly seaweed bio-packaging. Hip restaurants serve seaweed burgers and salads, not just to vegetarians, but to a broader public. Seaweed regularly features in cooking programmes, on recipe blogs and social media. It is also a popular mineral, vitamin and nutrient supplement. Ground-breaking research is underway for the use of seaweed in the treatment of a range of chronic diseases, with medication for the treatment of Alzheimer's in the meantime approved by regulatory authorities. Moisturisers containing a high percentage of seaweed promise a youthful complexion.
Even in areas far from the ocean, farmers are using seaweed biostimulants to regenerate soil health, ordering stock via an easy-to-use trade system linking them directly to the seaweed supplier of their choice. These farmers also regularly use seaweed as a health supplement for animals. Technical equipment is sometimes powered by a highly efficient seaweed biofuel, made from seaweed processing by-products.

In this 2030 future, seaweed is also recognised as an integral part of the broader ocean agenda by local and international politicians and political institutions alike. The expansion of the industry has been supported by cross-border knowledge transfer and dedicated grants. The broader ocean community has integrated seaweed into its narrative surrounding ocean protection and climate change, recognising its role as a European champion. The seaweed community in turn is a strong voice in efforts to restore ocean health and is celebrated for its societal and environmental impact as much as for its exponential economic growth.

The benefits and potential of seaweed have been extensively researched and proven by science. The industry has prioritised additional research areas to help foster sustainability as the industry grows. Scientists and stakeholders from along the value chain work in close exchange, relying on sophisticated data collection instruments and sharing data openly. Seaweed farms cultivate a mix of species using different farming techniques which are taught at specialised seaweed academies. Cultivation locations are chosen in alignment with scientific insights and MPAs under the 30x30 ocean protection agenda.[5] Many seaweed farms are integrated with other aquaculture, such as salmon, or co-located with offshore windfarms to maximise environmental and economic co-benefits. Installations of this kind are the preferred approach for new operations. A share of the value generated through the growth of the industry is reinvested into local economies, supporting for example education efforts surrounding the ocean and climate change.

Seaweed farms are gradually reverting the biodiversity loss in coastal ecosystems, they clean water from excess nutrients and reduce acidification. Carbon credits systems are well established and accepted at political level and enshrined into the National Determined Contributions (NDCs) that are at the heart of the Paris Agreement.

Small players are as much part of the industry as larger incumbents, with a balanced mix of community-led cooperatives, innovative start-ups and larger corporations. The smaller players of today have developed into sophisticated companies with secure turnovers. Seaweed start-ups are part of a thriving community, supported by dedicated accelerators and investment.

Stakeholders understand the need to work together in order to maximise sustainable growth along the value chain. A weak link in the value chain network is seen as a collective issue and solutions are developed jointly with the benefit of the industry in mind. Everyone along the value chain can make a living wage and promising job opportunities exist independently of age, gender identity, background or education. A career in the seaweed industry is seen as a safe bet and competition to work in this fascinating space is fierce.

5. The 30x30 agenda is a call from leading ocean scientists to achieve the protection of 30% of the ocean by 2030 through the creation of dedicated MPAs in which (potentially) harmful practices are prohibited. For more details see: https://www.greenpeace.org/international/publication/21604/30x30-a-blueprint-for-ocean-protection/

Cultivation and processing facilities have been created in adherence with ecological best practices and are embedded within the existing landscape, both on land and in the ocean. They play an important role within the local community, providing learning opportunities and a cultural space both to businesses and individuals. Seaweed farms and processing facilities are open to interested visitors for tours and offer knowledge-building workshops. In schools, seaweed is on the curriculum from the very start, even in non-coastal areas, with pupils being taught about the benefits of this regenerative material.

Innovation is driven by industry, science and consumers of all ages, for example through cross-continent research efforts, school science competitions, hackathons and ideation with incumbents. Product development focuses on the creation of new products as well as the refinement of existing ones, with the objective of increasing efficiency of material use e.g. through the development of innovative by-product applications. New products consider and anticipate customer needs, with a focus on environmental and health benefits.

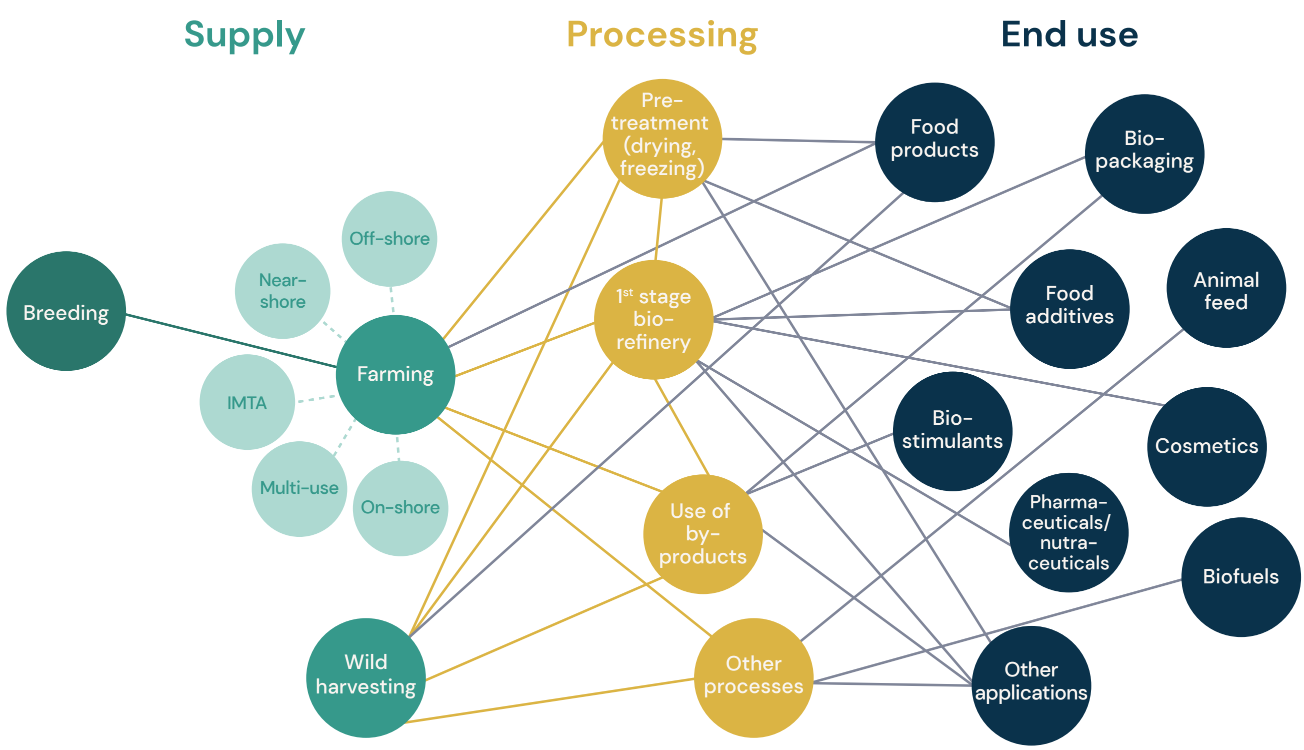
Foundations for a sustainable European seaweed industry

A key element in unlocking the full potential of seaweed to create such a thriving European industry by 2030 will undoubtedly be the creation of a strong and sustainable value chain.

First, there is a need to determine what this value chain might look like. Value chains are commonly perceived as a linear sequence of activities, with a clear start and end point. The seaweed industry, however, is anything but linear. Even today, the value chain already includes a variety of interlinked paths and activities with different feedback loops. Depending on the respective end-product application, seaweed species are grown using different methods. Seaweed is also processed in a variety of ways, sometimes in several processing cycles. End products are created either directly from cultivation or following processing and in separate sub-segment production value chains. As the industry grows exponentially, this web of activity will increase in complexity.

As a result, the seaweed value chain must be considered in a much more dynamic, interconnected manner, consisting of three distinct parts, i.e. (i) supply, (ii) processing, and (iii) end use, which respectively are made up of different components (Figure 13).

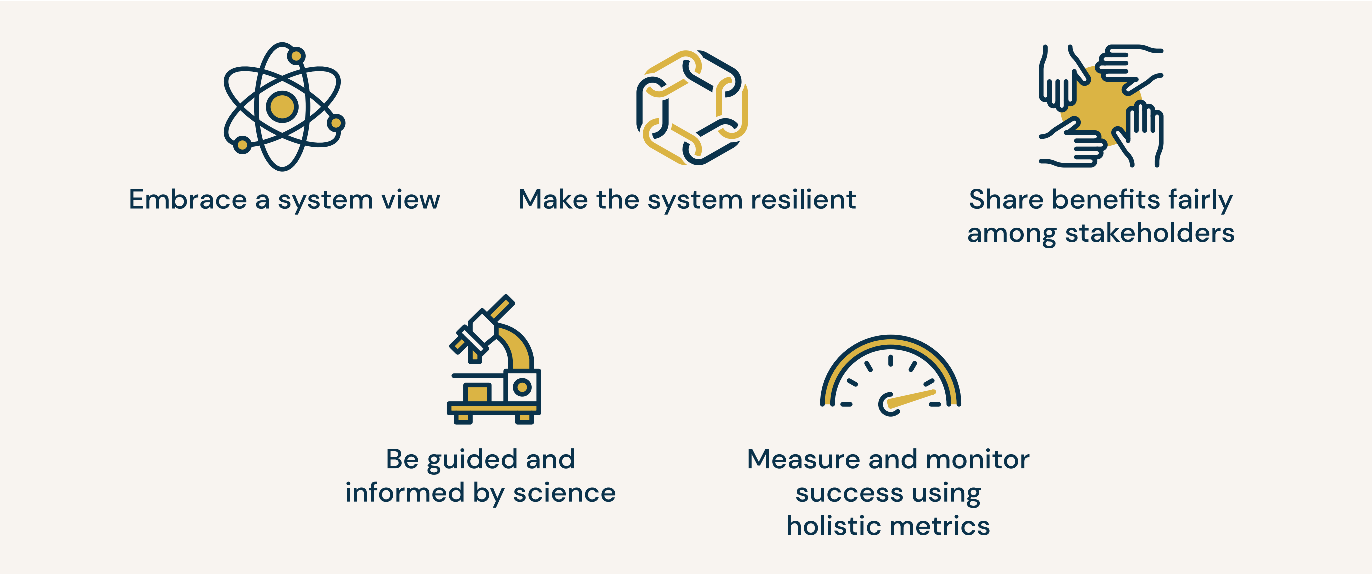
Figure 13 – Dynamic seaweed value chain visualisation (simplified)



Supply includes the different types of aquaculture production, ranging from community-led coastal farming to large-scale offshore farming and their preparatory stages, as well as sustainable wild harvesting. Processing includes activities such as pre-treatment and biorefinery, as well as the reuse of processing by-product waste and other processes. Finally, end use consists of the respective value chains for the different seaweed-based end product segments, for example food, alternative packaging and biofuels.

To ensure long-term sustainability, five guiding principles must be embedded deeply within the structure of this value chain (Figure 14). These principles provide a set of common tools for industry stakeholders to apply as they expand activities.

Figure 14 – Guiding principles for the creation of a sustainable seaweed industry



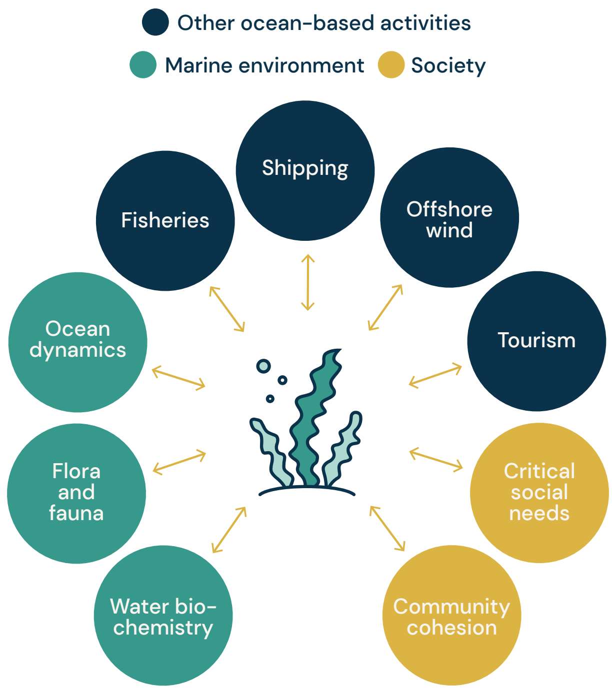
Principle 1: Embrace a system view

The ecological, social and economic systems we operate in are closely interlinked, with events and behaviours in one system often causing reactions or knock-on effects within the same or across other systems (Lubchenco, Cerny-Chipman, Reimer & Levin, 2016). It is essential for seaweed stakeholders to understand this point, and acknowledge the industry's close links with other marine ecosystems, the broader ocean economy, and the wider socio-economic system (Figure 15).

Any activities undertaken by stakeholders must be designed to maximise positive environmental and social impacts and factor in potential feedback loops or rebound effects, rather than solely focusing on benefits for the seaweed industry. This principle will become increasingly important as the industry grows in size, with significant scaling likely to have an impact – negative or positive – on the ocean and beyond.

Several examples demonstrate what this means in practice:
Marine environment
The ocean comprises many different ecosystems and ecosystem actors which contribute to the functioning of the ocean. Changing this delicate balance can have far-reaching consequences and butterfly effects on the marine environment. Introducing non-native seaweed species, for example, may affect other species severely which in turn

Figure 15 – Taking a system view for the seaweed industry



could create an imbalance in the wider ocean (Barbier, et al., 2019).

At the same time, an understanding of how the ocean functions can also help determine potential opportunities to multiply the positive effect seaweed can have within the system. The strategic placement of seaweed farms, for example, could foster (nursery) habitats for marine animals, thus increasing species diversity.

Other ocean-based activities
A growing number of stakeholders with differing agendas and interests are using and exploiting the ocean. As the seaweed industry grows, it will be essential to anticipate potential conflicts with other users such as fishers or tourism operators. In doing so there is a strong opportunity to identify beneficial synergies, for example through sector coupling in the form of integrated multi-trophic aquaculture or multi-use scenarios. Seaweed aquaculture could thus be integrated with salmon or shellfish farms, or co-located as part of offshore windfarms (see more details in Chapter 3). In addition, the seaweed industry will only thrive sustainably if integrated into a holistic ocean approach, for example through inclusive marine spatial planning.

Society
The material footprint and rate of consumption in Europe is already at an unsustainable level, with many producers taking a take-make-waste approach. To avoid stretching the system even further beyond its limits, the development of new seaweed-based products should be driven by the fulfilment of critical societal needs and with the aim of reducing material use. Product innovation could for example focus on replacing particularly carbon-intensive products with more sustainable seaweed-based alternatives.

Principle 2: Make the system resilient

Recent events have highlighted the fragility of our existing systems in dealing with unexpected shocks. As shocks of all kinds – be they climate or health-related or of an economic nature – are expected to occur more frequently in the future, it is essential to create resilient foundations. In times of crisis, the industry should then be able to rely on these foundations to rapidly bounce back and maintain a positive growth trajectory without having to undergo significant changes to its functional integrity.

This can be achieved by
Ensuring diversity and redundancy: Rather than focusing on a silver bullet for seaweed growth, the industry should promote diversity, supporting sustainable wild harvesting as well as different types of aquaculture (ranging from community-led, small-scale coastal farming to mid-size near-shore farming, large-scale offshore farming, and onshore farming). Sustainable practices must be adopted across the board. Stakeholders should further explore a breadth of native species with different properties, in line with segment growth expectations detailed in Chapter 1. In creating this redundancy, the industry can mitigate the risk associated with single-method cultivation or monocultures and increase its ability to withstand crop losses or failures, caused for example by disease or unexpected shocks.

Minimising waste: The entire value chain should be built to maximise efficiency. Material efficiency can be achieved for example by employing technological solutions with early warning systems to monitor crop progression and health, finding innovative new uses for seaweed processing waste products, or maximising the valorisation of co-products. Manpower and tools can be employed efficiently across the industry by pooling knowledge and resources, for example through the sharing of equipment or the attachment of new operations to existing aquaculture operations.

Creating flexibility and adaptability: Processing capacity must be created in a modular manner which allows for easy equipment reconfiguration to adapt to different types of processing, seasonality in supply and fluctuating demand. In addition, to minimise downtime and broaden use scenarios, innovation should focus on creating alternative use solutions for times of inactivity in refineries.

Principle 3: Share benefits fairly among stakeholders

Lessons learnt from other industries serve as a pertinent reminder of the negative consequences the unbalanced distribution of wealth and power can have. In the agricultural sector, for example, high suicide rates are prevalent among overworked farmers struggling to make ends meet financially as they face increasing pressure from big corporates to lower their prices (Kutner, 2014). During the COVID-19 crisis, in turn, many garment workers in the developing world fell (back) into poverty as large fashion players cancelled orders without fulfilling payment obligations, leaving them with no income or other form of support (Grant & Carroll, 2020).

Fairness, however, is an integral part of a well-functioning industry and an even more important pre-requisite for the pursuit of long-term sustainability. As such, it is included as one of the objectives in the Convention on Biological Diversity (United Nations, 1992). Above all, it creates trust and a sense of community, thereby strengthening the value chain. Stakeholders who feel valued and know they will ultimately benefit from time and energy invested will more readily do their part and work towards the success of a common goal. There is also less of a risk that parts of the value chain break away due to financial pressure over time, causing unpredictable knock-on effects for the rest of the industry.

This holds particularly true for the seaweed industry. As we have described, to grow the industry the creation of an integrated supply chain and simultaneous stimulation of supply and demand are essential. A symbiotic, trusting relationship between producers, processors and buyers is a core enabler in this context, as no part of the seaweed value chain can grow significantly without the others. If stakeholders see themselves as part of a joint community with shared principles and in pursuit of a common goal, such a relationship can be established. In light of this, seaweed stakeholders should ensure mechanisms to safeguard a fair distribution of benefits, such as an agreed minimum wage, are put into place.

Principle 4: Be informed and guided by science

Scientific research has highlighted the significant potential of seaweed, in particular with regards to the environment (see for example Froehlich, Afflerbach, Frazier, & Halpern, 2019 or Theuerkauf, et al., 2019). Such research serves as an excellent starting point to understand the benefits a scaled seaweed industry could offer on an overarching level. As the seaweed industry grows, however, it will be essential to conduct more granular research, as many areas remain to be explored (Hasselström, Visch, Gröhndahl, Nylund & Pavia, 2018). In particular, additional research is needed to extend knowledge on basic principles of seaweed biology, genetics, physiology and biochemistry. Further, little is known on the potential impact of a scaled industry on the delicate ocean ecosystem or on the continued functioning of other ocean-based industries. A total seaweed carrying capacity of the ocean – if such a thing even exists – or the all-comprehensive carbon absorption and mitigation potential of seaweed in Europe have equally yet to be defined.

Close engagement with scientific institutions from the outset, but equally collaboration across disciplines (including for example biology, chemistry, mathematics, IT, engineering, economics, environmental and social sciences) will not only provide answers to many of these questions, but also inspiration and guidance, for example for high-benefit segments to expand into new applications or services. This will help convince policymakers and investors of the seaweed opportunity and create a fact-driven industry which maximises the observance of planetary and human boundaries.

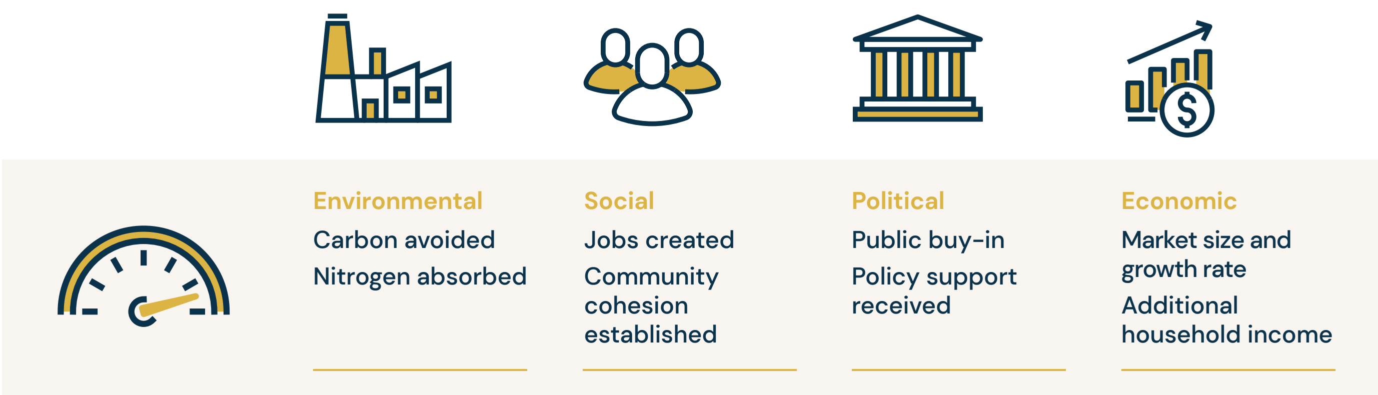
Principle 5: Measure and monitor success using holistic metrics

Questioning the existing system and striving to do better by creating a new sustainable normal is of little value if we do not equally question how success is defined and measured. It is therefore essential to move away from a philosophy focused purely on financial performance and take a new approach which both acknowledges the importance of observing planetary and human boundaries and celebrates and rewards efforts to remain within those limits. The creation of a system which collects comprehensive data on a range of factors also encourages more informed and responsible decision-making at both an industry and governmental level, enabling business leaders, policymakers and heads of state alike to drive more sustainable development (Fenichel, Milligan & Porras, 2020).

In order to make this possible in practice, seaweed stakeholders must define and introduce a mutually agreed range of specific metrics focused on environmental, social and political impacts to consider in addition to purely economic indicators such as market size and growth. Figure 16 provides an example of what such metrics could look like.

At the same time, the industry must also create a system to measure itself against these metrics and determine a way to ensure accountability in case of shortcomings.

Figure 16 – Example industry dashboard with potential metrics



While the creation of a sustainable industry is certainly no easy feat, the alignment around a common understanding of a target state and the definition of a shared approach of how to achieve this constitute important building blocks. The 2030 industry vision and guiding principles highlighted in this chapter seek to provide first guardrails in this regard. It is now for seaweed stakeholders to come together and paint in the details of this picture, with a view to creating an industry which reflects their diversity, respective interests and needs, and establishes a new paradigm for others to pursue.

CHAPTER III

Unlocking the potential: a roadmap to put the industry on the right track

The case for championing the European seaweed industry has been clearly established in Chapter I: seaweed could turn into a multi-billion-euro market, generate more than 85,000 full-time equivalent jobs, contribute to improving ocean health and to achieving the broader SDGs and the Paris Agreement's 1.5°C target. Principles for growing this nascent industry in a way which is systemic, science-based, resilient and leaves no one behind have been summarised in Chapter II. This final chapter complements the first two by proposing a system-based dynamic roadmap to move from theoretical potential to tangible growth and resulting business, job and ecological benefits. It also suggests a pragmatic "to do list" for immediate priorities to put the industry on the right track for scaling up in the next two to three years.

1. A system-based dynamic roadmap

The European seaweed industry will not have to start from nowhere. Wild seaweed has been harvested for centuries, and today around 300,000 tonnes of fresh seaweed are produced per year (FAO, 2018). However, the millions of tonnes that need to be produced to support the ambitious case detailed in Chapter I constitute a major leap up from this baseline, both in absolute numbers and also in the way seaweed is produced and processed.

Although seaweed farms and processors are on the rise in Europe, the industry still faces a "chicken and egg" challenge preventing it from growing at the rate needed to unlock its potential. Put simply, the challenge is that farmers and processors want to scale production capacity so they can increase volumes and drive costs down, but to increase capacity they need to receive long-term guarantees from off-takers for large volumes at a good price. On the other hand, potential off-takers – for instance food and beverage, cosmetics, or feed incumbents – see the value in sourcing high-quality, traceable European seaweed, but they complain they cannot find desired volumes at a decent price today and therefore naturally turn to cheap, imported seaweed from Asia (even though concerns are on the rise regarding its quality, traceability, respect of human rights and environmental standards) (Barbier, et al., 2019).

Breaking this vicious circle requires a systemic approach, which activates technology, finance and policies smartly to build the industry by stimulating supply and demand at the same time. This systemic perspective recognises that a sequential, step-by-step approach is unlikely to work. Instead, five main dynamics need to come to play in parallel:

A European demand needs to grow faster, accelerated for example by the development of innovative product and service applications and access to new markets.

B Production capacity needs to increase to serve as much of this demand as possible.

C At the same time, production costs must be decreased significantly.

D Production must be supported by cost-efficient and well-distributed processing facilities.

E An efficient bridge needs to be built to connect the demand and supply sides.

This final chapter describes and analyses the main drivers that need to be leveraged to support these five simultaneous dynamics, and provides specific and inspiring examples of innovative pioneers and initiatives that are already leading the way towards the creation of a scaled industry. As the list of actions proposed below is extensive (although it does not pretend to be exhaustive), this chapter also proposes six specific "triggers" to be prioritised in the next two years to tip the industry towards the right acceleration pathway. Seaweed for Europe will use this as a basis to guide Coalition activities in the next 12 months.

Case study

While the European and Asian seaweed contexts differ in many important ways, Europe can still take inspiration from the journeys of other countries. South Korea, for example, has grown from being a small player in the latter half of the 20th century to the world's third-largest seaweed producer after China and Indonesia. Importantly, this growth was driven by many of the same levers available to the industry in Europe today: a focus on innovation, efficient use of technology in processing and harvesting, and concerted actions by government to support the industry (Hwang & Park, 2020). With this in mind, the growth trajectory that could be unlocked in Europe seems by no means unattainable.

A. Boost European demand

Seaweed is increasingly permeating a range of European markets, and the trend is expected to continue in the coming decades. In addition, incumbents as well as innovators are investigating and developing new seaweed-based pilot products. Three main actions could accelerate this demand and help it evolve from niche to mainstream:

Raise awareness about seaweed products and their beneficial properties in the B2C and B2B markets: Today, the majority of potential buyers and consumers of seaweed are not even aware of the existence of seaweed-based products that could meet their needs. For many European citizens, seaweed is nothing more than an ocean species, with little use beyond food or as a raw material. These consumers and businesses need to be provided with the tools and knowledge to understand that this is in fact not the case. In particular, B2C consumers looking for healthy, low-carbon, ocean-friendly food and products need to be made aware of the possibilities and beneficial properties offered by seaweed. This will in turn result in positive demand signals to consumer goods companies and retailers, encouraging them to increase their seaweed product offering. Many tools across different media outlets can contribute to raising this awareness, including knowledge campaigns, newspaper articles, documentaries or even mainstream cooking shows.

Case study

CNBC, an American business and financial news network, released a video on its YouTube channel in September 2020 entitled 'Why Seaweed is About to Boom' – a 15-minute pitch of the industry geared towards consumers, including those without prior knowledge of the sector. The video aims to inspire by reframing seaweed as far more than a niche food product, presenting it instead as a profound opportunity offering holistic social, economic and environmental benefits. Its key messages include the potential for explosive growth in the seaweed market in coming years, low barriers to entry for suppliers, and the role of seaweed in regenerative ocean farming approaches. The video generated ~300,000 views in less than a week, clearly demonstrating consumer interest and receptiveness to the topic.

In the B2B segment, this awareness mission will take more natural business channels and needs to target executives, product development, marketing and procurement teams as a priority. This can be achieved through panel discussions in targeted conferences, and engagement with industry associations and coalitions like Seaweed for Europe. Again, a significant part of the puzzle is to create a general awareness of the benefits seaweed can bring. States, regions and city authorities can also contribute significantly through public procurement, for instance by proposing seaweed-based food in school canteens or buying seaweed-packaged products.

Accelerate product development: The integration of seaweed as an ingredient in product formulations or of seaweed-based products in company portfolios is no easy task: industrial and commercial tests must be passed, and

> "As the Coalition steps up its pace, we call on all interested stakeholders to work together in creating an integrated and forward-thinking industry"
>
> Vidar Helgesen, Co-Chair of Seaweed for Europe, Special Envoy for the Ocean of the Norwegian Ministry of Foreign Affairs

legal prerequisites must be met. For corporates, this requires cross-function collaboration and coordination between R&D, marketing and finance teams. Corporates can facilitate this process by creating mixed teams with a specific mission to integrate seaweed into the company offering. Following this development, marketing teams need to be on hand to attract new customers to the products.

Case study

Orkla – a leading Norwegian consumer goods company focussed on the food sector – demonstrates a spirit aligned with the development of sustainable ocean-based products. Orkla has been vocal about its commitment to embedding sustainability within its business model, and joined the UN Global Compact in 2015, placing the SDGs firmly on its agenda. In line with those principles and capitalising on its prominence in the Norwegian food market, Orkla is actively assessing the role seaweed can play in its business in the future, exploring innovative applications in packaging and its potential as a major or minor ingredient in food products. To achieve this, cross-functional collaboration and knowledge-sharing within the organisation will definitely be required. As a first step, Orkla recently set up an ocean-focused subsidiary, which has already acquired shares in a Norwegian seaweed producer (Orkla, 2020).

Product development can also occur through new start-ups proposing innovative products to the market. Such seaweed ventures need to be supported by dedicated acceleration of incubation programmes and to appear on the radar of early-stage investors as tangible and viable investment opportunities. In both approaches, it will be critical to leverage capabilities and expertise from various players in the value chain, for instance working hand-in-hand with seaweed farmers and processors.

Case study

German start-up Nordic Oceanfruit is one example of a venture bringing innovative seaweed products to market. Already present in large supermarket chains with its range of seaweed salads which reflect the ocean flavours of countries as diverse as Norway, Italy and Korea, its next foray focuses on the creation of a plant-based alternative to tuna under the brand Betterfish – using seaweed as an ingredient. Nordic Oeanfruit's initiative is supported by leading tech-accelerator TechFounders (Nordic Oceanfruit, 2020; UnternehmerTUM , 2020).

Adapt and clarify seaweed product certification and safety standards: The route to market for seaweed-based products or ingredients in Europe is complicated by safety standards that are not fit for purpose, and a lack of clear certification. Coupled with an absence of operational safety standards, for example in relation to workers' safety or biosecurity, this is impeding the insurability of investment and consequently the growth of the industry.

The food, food additive and supplement markets are among the sectors impacted by a lack of clarity. Under the European Commission's Novel Food regulation for example, a seaweed species is only authorised as a food if it is on the list of novel foods or its consumption in the EU prior to 1997 has been demonstrated (i.e. it is deemed non-novel). In all other cases, a lengthy authorisation process is required before a species can be used. As the legislation, however, does not include an exhaustive list of seaweeds authorised, it is difficult for stakeholders to ascertain the status of specific species (Barbier, et al., 2019)

A further illustration of safety standard challenges is the case of arsenic, which can be toxic to humans and animals, but mainly in its inorganic form (CORDIS Results Pack, 2019). Seaweed does contain high amounts of arsenic, but it is principally found in its harmless organic form. The total amount of arsenic contained in seaweed used for animal feed is monitored, but the monitoring may not differentiate between its harmful inorganic and harmless organic chemical forms. This results in some seaweed products being forbidden as they are above the legal threshold, although in reality they do not pose a danger. Changing this overall arsenic limit to a threshold value based only on the hazardous inorganic arsenic could make a real difference in mainstreaming seaweed-based products in feed, without causing any health or safety issues (Barbier, et al., 2019). Research is needed to help inform policymakers with clear scientific guidance and support, and to convince them of the need to make such changes.

Case study

The SilhouetteOfSeaweed research programme (2015-2017) gathered various academic institutions to estimate the toxicity of arsenic in a variety of seaweed species. It eventually helped inform European Food Safety Authorities about the risks associated with arsenic, and is a good example of how science can drive policy efforts (European Commission - CORDIS EU Research Results, 2015).

To justify investment into such research and draw attention of policymakers to these seaweed safety standards, the industry needs to send signals. This is where a coalition like the Safe Seaweed Coalition can add significant value. The Coalition was established by the UN Global Compact and the

Lloyd's Register Foundation in response to the challenging and fragmented landscape for seaweed safety standards and regulations, and is hosted by Station Biologique de Roscoff (CNRS/Sorbonne in France) – a world-leading "seaweed centre" with a strong global network. In line with its central tenet – that working towards shared goals on safety fosters collaboration, not competition – the Coalition will engage multiple industry stakeholders to work together in pursuit of global safety standards and regulations for seaweed products, employees and marine environments.

B. Scale European production capacity

A robust demand for high-quality, traceable, sustainably grown seaweed is key to growing the European market. However, if this demand is met through imports, Europe will miss out on many of the benefits associated with seaweed farming (e.g. innovation, ecosystem services, coastal jobs). Chapter I analysed each segment and sub-segment of seaweed products and concluded that roughly 30% of the 2030 European seaweed market can be supplied with locally grown and processed seaweed. This translates into millions of tonnes of fresh seaweed each year, which is far above current production levels. While Europe can build on expertise and know-how from decades of wild harvesting and processing, production growth of this magnitude will depend on cost-efficient farming and processing scale-up, which must meet sustainability criteria as detailed in Chapter 2. Today, cultivated European seaweed is insufficient in volume, too expensive and produced by a fragmented supply chain. So far only a few companies have managed to secure a license for large-scale operations and leverage sufficient funding to expand.

Case study

Algolesko, a French seaweed company, provides an example of how cultivation at scale in Europe can be sustainable and support the wider ocean agenda. In 2013, the company secured the right to farm 150 hectares of ocean off the coast of Brittany. This farm sits within a Natura 2000 site - a nature protection area designated by the EU to promote biodiversity (Algolesko, 2020).

In August 2020 Ocean Rainforest, a Faroe Islands-based company cultivating seaweed in the open ocean, closed a US$1.5 million (€1.26 million)[6] investment round, of which US$850,000 (€716,000)[7] was invested by WWF, a conservation NGO which also led the process. The investment will enable Ocean Rainforest to grow its operations and support its ambition to more than double its harvest next year. While much more investment is still needed, this success demonstrates the potential for NGOs and the private sector to together deliver blended finance that can simultaneously scale up and de-risk investment in the seaweed space (Ocean Rainforest, 2020).

6 At an exchange rate of €0.8422 to US$1 on 5 August 2020 - the day of the news announcement (https://www.exchangerates.org.uk/USD-EUR-spot-exchange-rates-history-2020.html).
7 Ibid.

This second dynamic therefore focuses on growing the farming capacity, with three main drivers to achieve this:

Simplify, homogenise and streamline regulation for the establishment of new farms: Applying for a seaweed farming licence today is not common or straightforward. In fact, regulation constitutes a major hurdle for any entrepreneur or business wanting to set up a seaweed farm. In addition, licensing processes vary considerably between countries, making it harder for best practices to be shared or for companies to expand their efforts on an international scale.

This hurdle manifests in three main ways: (i) seaweed licence requests are evaluated against inappropriate criteria, i.e. those that are usually applied for finfish or shellfish farming, rather than their own set of specialised regulations; (ii) the process is usually extremely complex to navigate – for instance in France applicants need to verify their request is compliant with regulations at national, departmental and local levels (Barbier, et al., 2019); and (iii) the process timeline is at odds with the realities of launching a business – a two to three year process with an unsure outcome, as is the case for example in Ireland and Scotland, is likely to scare off potential investors.

There is, however, significant potential for these regulatory processes to be streamlined at a national level. Part of the solution relies on a clearer integration of seaweed in national marine spatial plans that coordinate and manage the different uses of the ocean in areas within national jurisdictions. EU Member States have until March 2021 to develop such plans and share them with the Commission. At the state level, proactive and science-based mapping of sites suitable for seaweed farming will accelerate the process when farm licence applications are received. The Commission can also play a strong influencing role in this dialogue between Member States and Brussels. While the revised guidelines on aquaculture are expected to cover seaweed in some form by the end of 2020, the creation of a dedicated set of seaweed-specific guidelines would facilitate the process.

Another key success factor is the licence to operate, i.e. when local stakeholders – from coastal communities to other ocean users like fishers and mussel or oyster farmers – accept the case for a seaweed farm to be installed. In line with the need for the creation of greater awareness highlighted in Section A, these stakeholders need to be informed about the benefits (often overlooked) and the real disadvantages (often overestimated) of such farms.

Case study

The North Sea Agreement was developed through a joint consultation of all Dutch users of the North Sea, with the aim of ensuring an integrated evolution of ocean industries. The marine spatial planning approach in this document notably proposes that the authorisation of every new offshore windfarm is contingent on combined use of the relevant area with other sustainable ocean activities. Seaweed farms are mentioned as one way to use the space between turbines. The Agreement is currently being reviewed by the Dutch parliament (Government of the Netherlands, 2020).

Leverage existing aquaculture and ocean activities infrastructure to co-locate seaweed farms: In addition to improving the licensing process, parallel ways to fast-track the development of seaweed farming capacity can be explored through multi-trophic farming. Multi-trophic farming refers to aquaculture that grows species from different levels in the food chain in parallel. The two advantages of such an approach are (i) the leveraging of existing licences and infrastructure, and (ii) co-benefits from symbiotic relationships between these species.

A prime example is the integration of seaweed with finfish (e.g. salmon) farms, the latter being associated with environmental challenges including nutrient release (including nitrogen and phosphorus) in the surrounding ocean ecosystems. Seaweed can uptake a part of these dissolved nutrients, thereby mitigating eutrophication (SINTEF, 2012) in a process referred to as "bio-extraction" (Long Island Sound Study, 2019). Another possibility is to grow seaweed in conjunction with filter feeders, in particular bivalves like oysters and mussels, to smooth seasonality and generate year-round revenue from ocean activities with a different growth cycle. Taking these two examples to the next level would lead to Integrated Multi-Trophic Aquaculture farms, a very promising and symbiotic model on paper, but still to be proven, even at a small pilot scale. Finally, as mentioned in the North Sea Agreement case study above, the development of offshore wind farms in European waters could be an additional accelerator for seaweed farming capacity. The Wier & Wind consortium is aiming to make this concept a reality with a joint wind-seaweed facility to be deployed in the North Sea in the next 18 months (AtSeaNova, 2020a).

Train the workforce: The efficient and professional operation of these farms will require a new workforce of thousands of seaweed farmers, harvesters and hatchery specialists to be trained. Training can happen on the job, but it should be complemented by dedicated training programmes which provide an opportunity for industry novices to create new farms as well. In the short and medium term, NGOs, foundations and industry coalitions can help by providing tools and training to support these new joiners. In the longer term, seaweed should become part of the public education curriculum, to help foster early interest in careers in the sector and provide a foundation of knowledge to enable students to pursue related courses at universities or dedicated higher education facilities.

Case study

GreenWave, a US-based NGO promoting seaweed and bivalve farming, is currently developing a "Regenerative Ocean Farming Toolkit", with materials available online for new seaweed farmers to complement a dedicated training programme. This toolkit is intended to provide farmers with tools and a knowledge network to plan, obtain a permit and launch their own farms (Greenwave, 2020).

C. Drive production costs down

High quality, traceability and local sourcing are value-adds that can justify a price premium for European seaweed versus imported Asian products. However, European seaweed will not be viewed as an economically viable source of large-scale future supply if the price structure does not change – the current price premium often makes it ten times as costly as imports. To enable this change and help propel European producers up the ladder of preferred sources of supply, production costs in Europe have to be cut drastically.

Economies of scale will naturally occur as farms grow bigger in size and assets like boats or seeding and harvesting machinery can be amortised. Four additional drivers can together contribute to reducing production costs:

Improve yields: European farms have to catch up on decades of know-how in Asia and in particular develop expertise in increasing the yield of seaweed. It is crucial that the European industry learns from best-in-class players and techniques from other parts of the world, adapting them to native species and conditions. At the hatchery stage, selective breeding can help identify the most suitable and resilient species and crops to equip farmers with strong starting materials which can also help increase yield. Once spores are ready to be put in the water, new seeding techniques relying on spraying or gluing seedlings onto cultivation substrates can further help increase yield compared to traditional seeding twine (Kerrison, Stanley & Hughes, 2018). Finally, software and remote data sensors can contribute to a close monitoring of the development of the seaweed and help identify the best time for harvesting, when the optimum balance between quality and quantity is reached (Satpos, 2020).

Case study

Dutch company Hortimare has accumulated 10 years of experience specialising in selective breeding. Hortimare already works with several European seaweed farms to help increase the yields and quality of local species, for example providing starting materials that have been engineered to provide reliable production (Hortimare, 2020).

Leverage mechanisation and automation: While seaweed can be farmed in a very traditional and labour-intensive manner, the European industry should leverage its industrial know-how and innovation capabilities to mechanise and automate some steps of the seaweed farming process. Mechanisation and automation can be particularly useful at the seeding and harvesting stages. This will become even more important when farms reach a considerable scale (i.e. in the magnitude of more than 100 hectares).

Case study

Belgian company AtSeaNova provides technology to seaweed farmers, including industrial solutions to mechanise and automate seaweed farming – these include, for example, a floating machine that can seed, harvest and clean the substrate (AtSeaNova, 2020b).

Identify and develop new revenue streams: Another way to reduce seaweed selling prices without putting the economic health of farmers at risk is to develop additional revenue streams. Two main ideas could be further explored in this regard. First, the ecosystem services provided by seaweed farms could be monetised. Thus, carbon and nitrogen uptake could be monitored, accounted for, and traded as credits with companies or municipalities aiming to offset their production of CO2 or nutrients. In the US for example there is a growing momentum around oyster nitrogen credits in the Chesapeake Bay (Blue Oyster Environmental, LLC., 2020; Miller, 2020). A complementary route could be to develop eco-tourism revenue streams by organising visits to farming operations (on land and at sea), mirroring the growing "pescatourism" trend in fisheries (Lai, Cicia & del Giudice, 2016). However, it is important to manage expectations for these potential new revenue streams: they are not expected to constitute a significant share of revenue, but they can nevertheless help seaweed farmers gain additional income while maintaining competitive prices for the seaweed they sell.

Case study

BlueCs is a newly established company specialising in monetising ecosystem services so they can be traded and bought as a virtual service/product by companies or individuals, with revenues redistributed to the producers operating regenerative practices at the origin of the ecosystem services (BlueCs, 2020).

Share best practices and tap into relevant expertise: The last driver to reduce costs relies on the sharing of best practices, networks of experts, tools and equipment within the industry. In a non-competitive way, and for the sake of the industry, it is crucial that farmers from various European countries connect with each other to share their personal experiences and their knowledge on how to optimise production volumes and qualities. This dialogue can be facilitated by industry associations or coalitions at European level (e.g. Seaweed for Europe, European Algae Biomass Association), at regional level (e.g. Seaweed Alliance in the UK, Noordzeeboerderij foundation in the North Sea) or national level (e.g. Scottish Seaweed Industry Association, Norwegian Seaweed Farms, France Seaweed Industry Chamber). This networking can also help farmers identify the best solution or technology providers for efficient and proven turnkey solutions. In doing so, the cost for research, development and testing (and potential failure or low performance) of machinery, materials or moorings does not have to be internalised by each farmer individually, but can be shared. Finally, sharing tools and equipment, for example during different harvesting cycles, can provide additional cost benefits.

D . Scale and optimise processing capacity

European production will only have a role to play if the seaweed can be efficiently processed and turned into higher value products, and if production is done in a closed-loop manner where all by-products are valorised. Processing is a critical component of the value chain in achieving this. As a result, processing capacity has to be increased in line with production growth. Two types of processing infrastructure, both facing different challenges, are relevant here: (i) freezing/drying and (ii) bio-refinery.

For most European species suitable for cultivation, the farming process is quite seasonal with a harvesting period around spring. To ensure the quality and properties of seaweed are preserved for use throughout the year, it is essential to dry or freeze harvested seaweed as soon as possible if it is not consumed directly. This allows for continuous processing all year round. As a result, scaled freezing and drying infrastructure are critical. However, as these are only used two or three months per year, such facilities are very difficult to amortise economically. Several solutions to this issue can be explored: first, for small and medium-sized farms that do not reach a scale that justifies owning freezing/drying facilities, cooperatives and shared services can make a difference. Second, perhaps more importantly, solutions involving other land-based industries, such as the agricultural sector, should be explored. For instance, drying equipment could be shared among multiple users, e.g. farmers who want to dry aromatic herbs or berries in the summer, farmers who want to dry mushrooms in the autumn and farmers who want to dry apples in the winter. Freezing capacity in turn could potentially be shared with the meat and fish industries. As financing such infrastructure may not constitute the most attractive play for private investors today, public money could be smartly blended to provide guarantees, help de-risk deals, and increase the returns for private capital.

In addition, for Europe to develop a competitive edge, it is will be crucial that first-rate products are extracted through bio-refinery processes. As a result, a significantly scaled-up bio-refinery infrastructure will be needed. Bio-refinery can also help maximise the output generated from seaweed, for example through the re-use of first-stage bio-refinery by-products (to create e.g. biostimulants), achieving the double benefit of minimising waste and generating extra income streams. Bio-refinery processes are in particular pivotal to support the development of promising segments such as food ingredients, nutraceuticals and bio-packaging.

Case study

Oceanium, a biotech company based in Oban, Scotland, has developed a proprietary "green and clean" biorefinery technology to process seaweed into high-demand products including plant-based food and nutrition ingredients (e.g. protein, bioactives), and home-compostable, marine-safe bio-packaging. Oceanium's mission, by creating a market for sustainably farmed seaweed, is to enable the nascent seaweed farming industry and pioneer the development of a new, environmentally-friendly aquaculture industry in Europe and on a global level (Oceanium, 2020).

Algaia, a French biomarine ingredients company with a focus on seaweed extracts, acquired an alginate manufacturing plant from Cargill in 2016. Under Cargill's management, alginate was the plant's sole output, and residual seaweed left over from processing was discarded. On acquiring the plant, Algaia stated its intention to leverage its core skills in extraction to valorise by-products of the alginate production process, thereby maximising revenue and resource efficiency while minimising waste (Michail, 2016).

Science is actively working on optimising bio-refinery processes, and a growing number of innovators are positioning themselves in this part of the value chain (e.g. Oceanium, Origin by Ocean, GENIALG).

E. Professionalise and industrialise connections between European demand and supply

Growing demand and growing European production will not turn into a successful industrial (and ecological and social) story if industry supply and demand are not connected with each other. If incumbents in the domains of food, feed or others decide to replace a significant part of their portfolio products with seaweed-based alternatives, they need to be able to secure scaled and reliable sources of raw materials. This is not yet possible: a large incumbent procurement team would currently need to reach out to, negotiate prices and contract terms with a myriad of small players in various European countries to secure a large enough cumulated volume.

A first no-regret move therefore is to maintain up-to-date mapping and landscaping of seaweed producers and players in Europe. Such initiatives already exist, but they need to become more user (and business) friendly to act as enablers for simple supply/demand connections (Figure 17).

In addition, there are opportunities to develop new activities in the brokering and trading space to facilitate these transactions. This could represent a diversification opportunity for established traders in the seafood market, used to mediating between small operations and large-scale processors or end users like supermarkets. A dedicated virtual seaweed marketplace could be an additional seaweed-specific intermediary, ensuring that transactions succeed and are certified as fair for the farmers.

Case study

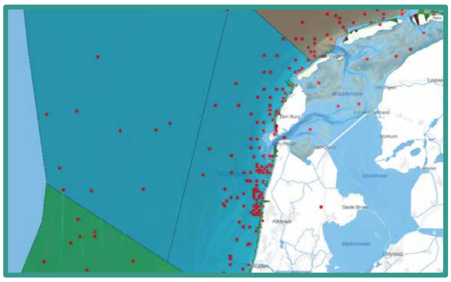
Macro Cascade is a project bringing together the seaweed industry, universities and research centres to prove the concept of a cascading seaweed biorefinery. The project aims to demonstrate both the technical and economic viability of the biorefinery concept, and it has a far-reaching set of goals to support this ambition. Specific objectives for the project include developing scalable extraction methods for the co-production of alginate, fucoidan, mannitol and protein from brown seaweeds; patenting new products in the feed, food and pharma sectors; and devising sustainable business cases to serve as a blueprint for the cascading seaweed biorefinery (MacroCascade, 2020).

2. A pragmatic "to do list" for immediate priorities

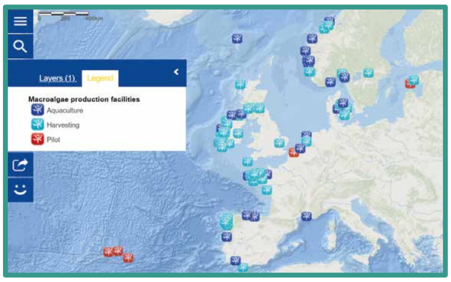
The breadth of actions that need to be undertaken more or less in parallel to grow the European seaweed industry can appear daunting at first glance. Embracing a pragmatic approach, this final section therefore proposes a list of priority "triggers" that can be advanced in the short to medium term to help remove major impediments and tip the system towards a sustainable and successful growth pathway (Figure 18).

Figure 17 – Examples of existing mapping and landscaping initiatives in the European seaweed space

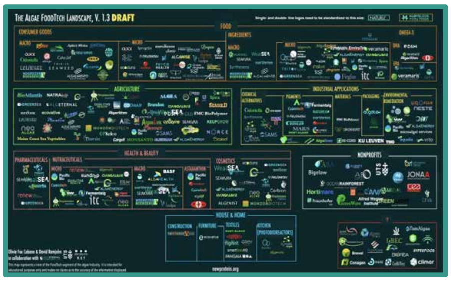
Aquaculture Atlas of the Noordzeeboerderij Foundation



Map of seaweed farms, harvesters and pilots, part of the European Atlas of the Seas of the EU Commission

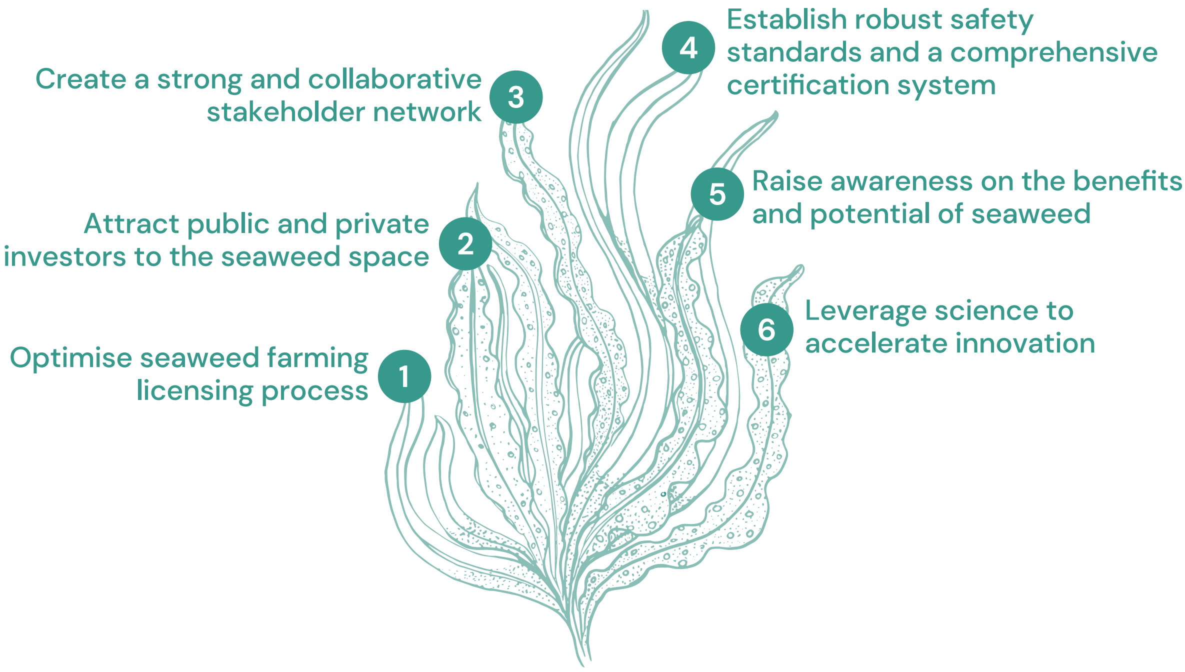


Algae food tech map, by Olivia Fox Cabane and David Ramjohn



Source: European Commission, 2020; Fox Cabane, 2020; Noordzeeboerderij Foundation, 2020

Figure 18 – Six priority action areas to tip the industry towards a pathway to sustainable growth



Immediate specific actions for each of these areas are suggested below. These will act as initial guidance for the Seaweed for Europe Coalition and steer the activities to be carried out in close collaboration and coordination with other seaweed initiatives and players in the field over the next 12 months.

1. Optimise seaweed farms licensing process

- At the EU level: provide suggestions to inform Strategic Guidelines for the sustainable development of EU aquaculture, and at a later stage develop seaweed-specific aquaculture guidelines at the EU level (for instance leveraging the recently released seaweed aquaculture guidance by the UN Global Compact).
- At the national level (working with two to three priority countries):
  - Develop suggestions for best-in-class seaweed farm licensing procedures. Building on examples of successful countries and adapted to local contexts, such procedures should lead to leaner, faster, better adapted licence request approval processes.
  - Develop an information toolkit targeted at future farmers to help navigate national licensing processes and share templates to include in licence applications.
  - Work with scientific institutions to identify spatial zones with high potential for seaweed farming.
  - Organise stakeholder consultations in zones with high potential for seaweed farming, engaging with local communities and ocean users to gain social licence to operate.
- Engage with salmon aquaculture incumbents and offshore wind developers to advance development of seaweed farms co-located with such activities.

2. Attract public and private investors to the seaweed space

- Raise awareness among conventional investors (e.g. family offices, VC and PE funds, banks) to elevate the seaweed opportunity as a valuable investment opportunity. This can be done through targeted communication materials, organisation of roundtables and workshops.
- Develop a comprehensive landscape of investment opportunities and a strong European pipeline of suitable targets, detailing key features of targets by European country and types of funds required (e.g. grants, equity, loans etc.). This landscaping exercise should be made publicly accessible to demonstrate the richness of the emerging European pipeline and facilitate deal-screening for investors.
- Convince European maritime authorities that industry growth will require a re-prioritisation of state or local authority funds towards the development of cooperative instruments including research, innovation and operation, that will secure seed provision for farming activities, organise market access and facilitate administrative activities, as well as providing training and capacity-building to seaweed farmers and workers.
- Earmark significant funding opportunities from public financial recovery and Green Deal stimuli (at Brussels and Member State level) that could be directed towards the

European seaweed industry scale-up, and investigate how these could be leveraged to de-risk private investments into seaweed.
- Develop the business case and blueprints for innovative, blended financing of seaweed infrastructure and apply it as a tangible proof-of-concept in selected geographies.

3. Create a strong and collaborative stakeholder network

- Rally seaweed players into industry associations and coalitions so they can meet and actively engage with their peers and other players across the value chain. Invite players from the broader ocean space to join for a diverse, inclusive and system-based dialogue.
- Empower seaweed stakeholders to develop a joint strong voice to use in discussion with policy- and decision-makers.
- Inform this network about the latest industry news, requests for collaboration or business development, research activities, policy developments and priorities.
- Organise working sessions and open dialogues to facilitate cross-border dissemination of knowledge and enrichment of networks. The creation of new connections between players at different steps of the value chain, e.g. investors with ventures, incumbents with suppliers and producers, and policymakers with the private sector as well as between complementary players to drive innovation is of particular importance.
- Establish mentorship and peer-coaching systems to help new entrants to the seaweed space benefit from knowledge accumulated by experienced practitioners.
- Centralise seaweed knowledge and make it available through online portals and resources in relevant languages.
- Maintain and update mapping and landscaping of European seaweed players, and make this resource available open source. Existing relevant information sources like EMODNET and European Atlas of the Seas are to be considered in this context.

4. Establish robust safety standards and a comprehensive certification system

The Safe Seaweed Coalition has already taken important first steps towards driving global safety standards/regulations and greater collaboration within the industry. The following safety issues lie at the core of its activities:
- **Product safety:** Address the lack of global food safety regulation for seaweed.
- **Safety of environment:** Establish standards which help determine the safety of any new seaweed cultivation operation for local ecosystems and livelihoods, with a view to preserving biodiversity and securing the support of coastal communities and investors, as well as to ease spatial planning and the procurement of a licence.
- **Occupational safety:** Ensure safe working conditions, in particular for those working in new and sometimes difficult environments.

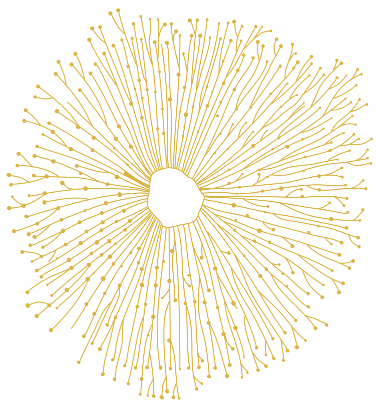
Outcomes will include (i) improved global standards and regulations for safe operation and production, (ii) improved public education/consumer awareness, (iii) more investment in scalable production initiatives, particularly in developing economies, (iv) greater collaboration between manufacturers, regulators, academia. IGOs, NGOs and industry and (v) leveraged funding from other sources.

To achieve this, the Safe Seaweed Coalition will gather new evidence and insights, map stakeholders, create technical working groups and develop partnerships. Further activities could include initiatives such as skills training, remote safety monitoring from drones and satellites, accelerator funding for small to medium seaweed projects, and real case demonstrations with large brands.

Seaweed for Europe will feed into these activities with the help of its members, providing a European perspective.

5. Raise awareness on the benefits and potential of seaweed

- Actively promote the seaweed industry's potential and solutions in all relevant policy, business and investment forums outside of the seaweed expert ecosystem. These include conferences with a business or policy focus (especially those not dedicated to seaweed), public stakeholder consultations, webinars, etc.
- Leverage knowledge networks and coalition activities in the various end-product segments to help off-takers understand the reasons for using seaweed-based end products and encourage innovators large and small to turn to seaweed as an alternative material solution.
- Promote the implementation of vast training and education programmes to strengthen the demand for seaweed, attract new industry players and close the gap between education offer and industry needs for workforce with relevant skills. This can take the form of introducing seaweed into school regimes (e.g. introducing children to the taste of seaweed), supporting blue school networks, courses for technical, financial and management skills.
- Engage with media, filmmakers, social media influencers, famous chefs etc. to spread the seaweed narrative.
- Organise seaweed knowledge campaigns engaging a range of different players including retailers to popularise seaweed, for example showing seaweed as a tasty, healthy, nutritious and climate-friendly food.
- Organise innovation challenges, hackathons and cooking competitions centred around seaweed.



6. Leverage science to accelerate innovation

- Establish close engagement between different scientific institutions to jointly define significant research gaps and develop a targeted research programme. One area could focus on extending CO_2 sequestration modelling and research to define a comprehensive emissions overview for all end-product segments, including natural sequestration potential, cradle-to-harvest emissions and end-product production emissions. Another gap is in current knowledge on the genetics of the main EU seaweed crops and the reproductive biology that is required for their domestication (Valero, et al., 2017).
- Engage the value chain closely in regular dialogue with scientists, for example through knowledge webinars, to enable innovators, technology experts and product developers to create sustainable and science-approved tools and products to match industry needs and support social and environmental responsibility.
- Develop a comprehensive database of different species suited to European waters, including information on yield and quality potential, environmental risks, and cost factors. Leverage existing farming operations to gather data to input into interactive spatial planning tools enabling farmers to choose where and with what species to extend their operations. Such tools could include location-based data, known environmental impacts of different species, and competing types of aquaculture in the relevant area.

With the vast potential seaweed can so clearly offer, all that is now needed is to find a way to unlock it. While the actions highlighted in this last section will constitute the first step in this direction, implementing them will require a collaborative effort from a diverse set of stakeholders with a range of knowledge, skills and expertise. We therefore invite you to join us on this journey and help us bring this hidden champion to the forefront of the European ocean agenda.

Appendix

European seaweed market in 2030: conservative, moderate and high ambition cases

Component	Ambition Level			Units
	Conservative	Moderate	High	
Animal Feed	539	1,192	2,218	€ million
Food	688	1,375	2,094	€ million
Biostimulants	607	764	1,824	€ million
Bio-packaging	182	569	1,283	€ million
Pharma & nutraceuticals	195	528	771	€ million
Additives	609	676	749	€ million
Cosmetics	149	215	291	€ million
Biofuels	6	12	22	€ million

European seaweed supply in 2030: conservative, moderate and high ambition cases

Component	Ambition Level			Units
	Conservative	Moderate	High	
Ocean surface area – at sea cultivation	7,696	14,876	26,266	Hectares
Land Area – on-shore cultivation	304	587	1,037	Hectares
Fresh weight	2,430,332	4,697,568	8,294,474	Fresh weight tonnes

Job creation in the European seaweed sector in 2030: conservative, moderate and high ambition cases

Component	Ambition Level			Units
	Conservative	Moderate	High	
Direct jobs	11,562	21,645	37,945	FTE equivalent
Indirect jobs	8,672	16,234	28,458	FTE equivalent
Induced jobs	5,781	10,823	18,972	FTE equivalent

Environmental benefits of the European seaweed sector in 2030: conservative, moderate and high ambition cases

Component	Ambition Level			Units
	Conservative	Moderate	High	
Nitrogen removal	5,772	11,157	19,699	Tonnes removed
Phosphorous removal	577	1,116	1,970	Tonnes removed
Net mitigation – natural sequestration	- 2,411	N/A	197,620	Tonnes CO_2e
Net mitigation – animal feed	- 429,808	N/A	5,001,817	Tonnes CO_2e
Net mitigation – bio-packaging	1,048	N/A	296,461	Tonnes CO_2e
Net mitigation – biofuel (gasoline)	6,532	N/A	37,170	Tonnes CO_2e

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