System Leadership, Technologies & Innovations along the Seaweed Value Chain for Corporate Sustainability

Sarah Elisabeth Peschko

Dissertation written under the supervision of Professor Stefano Pogutz, Bocconi University

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Sarah Elisabeth Peschko

Abstract

Facing climate change, degradation of resources and biodiversity loss, not only the environment but also economic and social well-being is endangered. Ocean based solution like seaweed has the capability to act as new paradigm for system leadership for social, economic and ecological well-being.

Seaweed offers sustainable alternative goods: *food, pharmaceuticals, animal feed, bioplastics, energy feedstock*, while it regulates climate through *nutrient level balance, oxygenation and CO2 sequestration.*

The thesis aims at the currently prevailing gap between managerial and ecological research streams within corporate sustainability. It aims for holistic system perspective and defines viable management-based strategies and technologies to mitigate declining ecosystem services and ecological resilience. Technologies with wider industry applications are identified which offers especially investor and managers a strategic insight for sustainable corporate reorientation and resource allocation, and act as global innovation forefront. The created system map and associated working streams therefore serve as guidance how to cocreate a sustainable multistakeholder ecosystem. By analysing pain points and possible interventions, an action plan for sustainable stakeholders and researchers is created. Direct implications for entrepreneurs and investors are further elaborated through creation of a multi-stakeholder platform and depiction of current viable sustainable business model of a seaweed venture. Guiding leadership strategies mindsets and perspectives are presented to fully leverage upon these opportunities.

By creating an overview and system map, this thesis may act as starting point for investors, politicians, researchers and entrepreneurs to understand the market from all perspective, rationalism, naturalism and humanism, and to combine these into sustaincentrism.

Keywords: Seaweed, ocean based regenerative solutions, Corporate Sustainability, Sustainable Aquaculture Innovations, System Leadership, Ecological Resilience Management

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Abstrato

A solução de base oceânica como as algas marinhas tem a capacidade de actuar como novo paradigma de liderança do sistema para o bem-estar social, económico e ecológico. Oferece bens alternativos sustentáveis: alimentos, produtos farmacêuticos, rações animais, bioplásticos, matérias-primas energéticas, enquanto que regula o clima através do equilíbrio do nível de nutrientes, oxigenação e sequestro de CO2.

A tese visa uma perspectiva holística do sistema e define estratégias viáveis baseadas na gestão para mitigar o declínio dos serviços ecossistémicos e a resiliência ecológica. São identificadas tecnologias com aplicações industriais mais vastas que oferecem especialmente aos investidores e gestores uma visão estratégica para a reorientação empresarial sustentável e a afectação de recursos, e actuam como vanguarda da inovação global. O mapa do sistema criado e os fluxos de trabalho e princípios orientadores associados representam, portanto, uma visão geral dos pontos de dor e possíveis intervenções e, portanto, como plano de acção para intervenientes sustentáveis. São apresentadas mentalidades, perspectivas e abordagens orientadoras de liderança para as alavancar plenamente.

Ao criar um mapa de sistema com recomendações práticas de fluxo de trabalho, pode funcionar como ponto de partida para investidores, políticos, investigadores e empresários compreenderem o mercado de todas as perspectivas, racionalismo, naturalismo e humanismo, e para os combinar no sentido do sustentocentrismo. As implicações directas para empresários e investidores são ainda mais elaboradas através da criação de um programa de incubadoras e da representação do actual modelo de negócio viável e sustentável de um empreendimento de algas marinhas.

Palavras-chave: Algas marinhas, soluções regenerativas baseadas no oceano, Sustentabilidade Empresarial, Inovações Aquícolas Sustentáveis, Liderança de Sistemas, Gestão da Resiliência Ecológica

Título: Liderança de Sistemas, Tecnologias e Inovações ao longo da Cadeia de Valor das Algas Marinhas para a Sustentabilidade Empresarial

Autor: Sarah Elisabeth Peschko

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Introduction – The greatest challenges for future business

"Law is to justice, as medicine is to health, as business is to___?"

In 2015, Donaldson and Walsh raised this fundamental question of the role of business. Walsh, Meyer, & Schoonhoven (2006) argue that business is serving the social development. From early on, business practices are understood as management of technologies and solutions, that aimed for human performance augmentations and efficiency. Especially, since industrial revolution, business innovations have emerged as the key driver for human development and economic prosperity (Bansal, 2002; Crane, 2013; Hart & Milstein, 2003; Margolis & Walsh, 2003; Bansal & Song, 2017). Management strategies e.g. JIT, international trade, hierarchal control, standardization, mass production enabled higher access to affordable food, health care and products. This led ultimately to exponential human population from 1.6 billion to today's 7.7 billion people, estimated to reach 9.7 bn by 2050 (United Nations, 2019). Furthermore, business solutions let markets flourish leading to a doubling of global GDP between 1992 and 2014 (Systemiq & Club of Rome, 2020). Humans have reached a land occupation and consumption level like no other mammal. According to the World Research Institute (2018) each person consumes 2.2 hectare whereas the planet's resources only offer 1.8 hectare per individual. Thus, human need 1.2 planets in order to sustain the exponentially growing population.

This has let however to negative consequences upon the resilience of the ecological environment. Human practices have led to resource degradation and a disruption of planetary boundaries, which makes human population more vulnerable to natural changes and catastrophes (Appendix I) risking stable food and resource supply. The changes within the ecological environment, from temperature, sea water rises to the degradation of the soil and acidification of oceans, has led to a great cost of economic markets and social well-being (Appendix I) (Brand 2009, Berkes et al. 2003). As Gladwin et al. (1995: 875) put it "how many organizations could exist in the absence of oxygen production, fresh water supply, or fertile soil?". The common business practices striving for efficiencies have led to gravel rebound effects upon economic markets from overfishing to monoculture chemical based agriculture to rising debt of the associated industries (SYSTEMIQ & Club of Rome, 2020). Current markets are not resilient to shocks, not socially just and depends on exploiting the nature, which has a negative feedback loop upon social and environmental wellbeing. European economy has become dependent upon imports, overoptimization and standardization, which are no fit for solving current socio-economic and ecological challenges (SYSTEMIQ & Club of Rome, 2020). Despite playing a central role in social and economic systems, the prevailing technocentric economic paradigm has denied biotic limits of the environment (Whiteman et al., 2013; Gladwin et al., 1995), underestimating the value of ecological systems towards business and society (Shrivastava, 1994).

Already in 1968, researcher Hardin defined human impact as tragedy of the commons, which depicts human short-term interest in contrast to the long term common good. He defines this human impact upon the environment as twofold. First being the growing population, thus the higher demand for natural resources and second being the way humans organize the extraction and use of resources, thus business (Dietz et al., 2003). With diminishing terrestrial material and agricultural productivity while the food demand rising up to 156% until 2050 (Ranganathan 2018), businesses are facing the greatest challenge of our times: closing the food vs land gap. For attaining the needed transformation in the way we perceive and extract resources, new sustainable business model innovations and markets need to be found that support environmental regeneration to maintain its human life vital ecosystem services for social and economic wellbeing.

Analyzing recent managerial, economic and ecological research as well as investment orientation the ocean emerges as one of the key future markets. The aquaculture is one of the fastest growing food sectors on the planet, with seaweed growing the fastest with 8% per year (Froehlich et al., 2019). Ocean and especially seaweed has been getting increasing attention due to its capability to serve human needs while regenerating the environment by European Commission's Blue Carbon Strategy, United Nations Compact's manifesto for a sustainable future and major investors like Jeff Bezos' Earth Fund. Seaweed is a very promising solution to derive more ecosystem services from the ocean (Tinch & Mathieu, 2011; Buschmann et al., 2017) while helping to mitigate climate change through 1. goods: *food, pharmaceuticals, animal feed, bioplastics, energy feedstock* 2. Its regulating capability: *nutrient, oxygenation and CO2 sequestration while protecting it* and offers three cultural services: enhancing biodiversity in fishes, thus tourism and economic activity.

Therefore, this thesis will further analyses the seaweed ecosystem, its potential, challenges and solutions based on managerial and technology sustainability research, acting as paradigm for sustainable business strategies for system change.

Literature Review

1. Ecological Setting – The Ocean

The ocean with a vast biodiversity of 228 540 species offers food, materials, energy and attracts tourism and impacts culture (Tinch & Mathieu, 2011; Dietz et al., 2003). It is defined as the 7th largest economy globally (Nunes & Ghermandi, 2013), its coastlines account for 61% GNP, 16% of animal feed proteins (World Bank, 2020) and sustains 350 million jobs and associated 3 billion live hoods worldwide (Seaweed for Europe, 2020). Beyond that, humans also benefit from the ocean in terms of ecosystem services (Winn & Pogutz, 2013; Fisher et al., 2009) e.g. regulating climate. 83% of current CO2 is going through oceans and coastal area e.g. seaweed has been defined to sequester 70% of the global CO2 (Chung et al., 2011), producing 54% of global oxygen. Seaweed is referred to as global lungs (UNESCO, 2019), outpacing rainforests. Every wet metric ton of seaweed can sequester 100kg carbon sequesters, and is one of the fastest growing plant (60cm per day), being more efficient in carbon offsetting than terrestrial solution e.g. forests (Bloomberg, 2020).

Nevertheless, these services also come to a disadvantage for nature. Through business-driven CO2 emission, the ocean acidifies which is life threatening to many marine species e.g. coral reefs, mangroves and seaweed have declined up to 35% (World Bank, 2020), triggering even further biodiversity loss measured at 100 to 1000 above natural levels (Rockström, 2009). Since 1970 oceans have trapped 93% of added heat by humans (IUCN, 2016). This can be seen by the projected changes and risks of increasing water temperature by IPPC (2019), depicting coral reefs, the habitat of fish diversity and kelp (seaweed) forests, sequestering CO2 (Fig.1) being greatly negatively affected by the rising temperature (Appendix II). If human activity continues as usual, CO2 level within oceans will further rise and marine species will be damaged, carbon sink capacity will diminish and possibly even release carbon with a reverse effect upon climate change (Bjerregaard et al., 2016).

Furthermore, continuous overfishing and nitrogen & phosphorus leaks into oceans (Morand and Merceron, 2005), combined let biodiversity and fish resources drastically decline, which does not only impact economic activities but also human culture (Lloyds & UN Global Compact, 2020). 75% of global fish being overfished, threatened to not regenerate (Winn & Pogutz, 2013), 60% of ocean's ecosystems are threatened and unsustainably managed (OECD, 2017) for the sake of low-cost materials, food efficiency and energy sourcing. Businesses have followed unregulated sourcing of materials and endanger simultaneously human health, social and (Gomez-Baggethun et al., 2010) economic well-being with currently USD 24 trillion in assets at risk due to higher temperature and the thus created sea water rising (Systemiq & Club of Rome, 2020). Furthermore, 124 million tons of nitrogen were produced in 2014 of which 15-30% leaked into the ocean (FAO 2015). This led to 245,000 square kilometers dead zones of fish and other marine species globally (Diazi & Rosenberg 2008), further pushing planet's biodiversity loss over the edge (Bjerregaard et al., 2016).

New solutions for sustainable energy, food and material solutions as well as new techniques to cultivate such must be found. These solutions must ensure continuous supply of goods while supporting the restoration of ocean ecological conditions and functionality for human longer-term wellbeing.

2. Redefining Business for System Change

Social wellbeing greatly depends on the natural abundancy of resources (World Resources Institute, Meridian Institute, & World Business Council for Sustainable Developmen, 2008), however instead of nurturing, these are steeply decreasing (Millennium Ecosystem Assessment, 2005). Oceans have become target of unregulated fishing, acidification, pollution and habitat destruction. As the Hardin already in 1968 defined it as a dilemma of the commons. Striving for optimized utilization of natural resources has brought about the opposite, a rebound effect.

The way we perceive business and execute strategies needs to transform fundamentally. This is further confirmed by the president of the World Business Council for Development, Peter Bakker "As a company we can reduce our carbon footprint dramatically. But the world's still driving off a cliff. We need a system change" (quoted in Whiteman et al., 2013, p.328). Business now needs to transform fundamentally, leaving common practices such as polluting fertilizer (nitrogen and phosphorous) (Ritchie 2019), heavy industrial land, water and energy footprint behind in order to sustain the previously triggered population growth and standard of life.

System thinking entails the appreciation of smaller systems interlocking to a complex bigger system, which will appear as unified whole (Bansal & Song, 2017). The challenge is that the system cannot be explained nor completely changed when focusing on just a few single processes. Thus, system theory emerges as promising guidance for holistic management of ecosystem services.
Thus, sustaincentric paradigm has emerged, which synthesizes the techno-mechanical worldview with extreme naturalism (Galdwin et al., 1995) in order to reach effective system leadership. The emerging corporate sustainability practices leverage upon technology and innovations to trigger a new "development that allows the present generation to meet our current needs, without compromising the ability of future generations to meet their needs" (Shrivastava, 1995; Bansal & Song, 2017). An example of such is to leverage oceans' potential for energy, food, medical and water sourcing. One of the main drivers for aquaculture and especially seaweed was found to be the growing demand for organic biomass. Biomass builds the basis for any sustainable alternative, from food, products to energy. Shifting resource consumption to be more responsible and sustainable, bio-based feedstock becomes of vital importance in any business strategy. Nevertheless, what is often overseen is that currently most sourced biomass feedstock e.g., sugar cane and corn are agricultural products and thus land, water and fertilization intense. These conflicts with resources needed for the expected human population growth by 2050. Seaweed instead does not occupy any land, nor does it need water or fertilizer. Seaweed biomass offers benefits for various industries i.e. food, additives, cosmetics, animal feed, textiles, bioplastics, biofuel and pharmaceuticals and thus has a high impact if rightly executed.

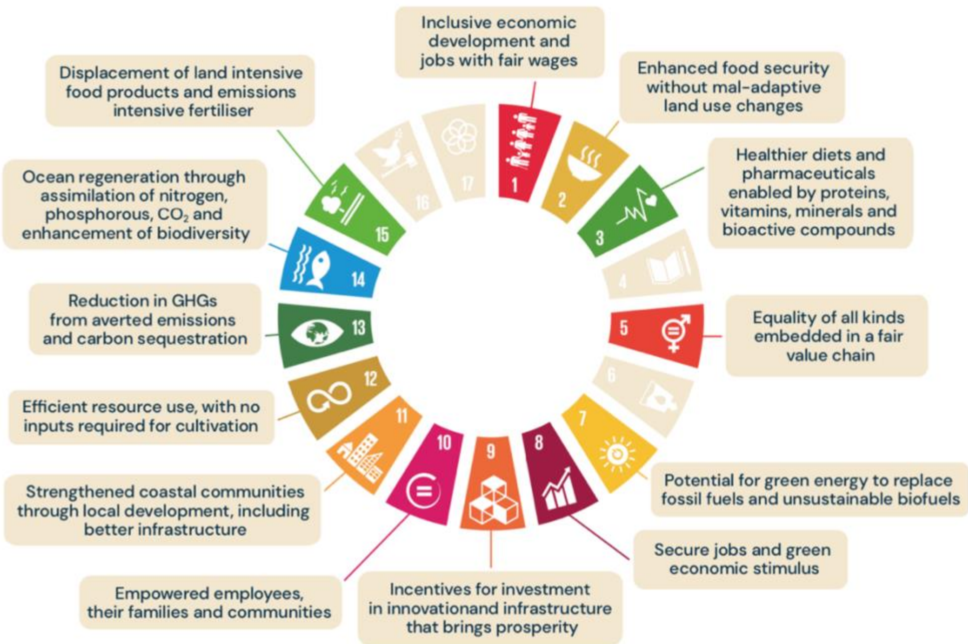
However, only if the ecosystem is understood holistically the appropriate research and development may emerge to further scale current impact. According to Bansal & Song (2017) a system cannot be fully understood nor utilized by its separated parts, it needs a holistic perspective in order to grasp the complex relationships. *"(...)one must understand the relationships among the parts in order to understand a system's organization, functioning, and outcomes"* (quoted from Bansal & Song, 2017, p.106) . Human stressors have led to a loss of ocean resilience, "the capacity of a system to absorb and re-organize while undergoing change so as to still retain essentially the same function, structure, identity and feed- backs" (Folke, 2006, p. 259). Being part of a complex food, fauna web of the ocean as well as carrying an essential role in nutrient and CO2 absorption, scholars call for resilience based adaptative management (ARBM). ARBM bases itself upon the dynamic relationship theories between ecological and social system and emerges as impactful leadership type across marine and terrestrial resource management (Kenneth, 2014, Argent, 2009). Bansal & Song (2017) supports this adaptive approach by referring to the dynamic and complex nature of the marine ecosystem itself. Until now management theories followed a rather static logic for objective definition and production infrastructure.

3. Solution Analysis – Seaweed

Following the approach of ARBM, this thesis will first deep dive into seaweed characteristics and different roles in terms social, environmental and ecological benefits along the Sustainable Development Goals defined by the United Nations (Figure 1). This will enable the vital understanding of the dynamics, interconnection and multi-dimensional drivers of seaweed and the different actors affecting and affected by seaweed. This creates the basis for effective strategy formulation.

The coalition Seaweed for Europe (2020) summarized seaweed capability to substitute energy and emission intense activities like human food, animal feed, plastic alternatives as well as its emission offsetting for the European market (Appendix VII). By 2030, if scaled seaweed could offset climate change with 5.411 million tons of CO2 in Europe (Seaweed for Europe, 2020).

Figure 1: Seaweed impact upon SDGs (Seaweed for Europe, 2020)



3.1 SDG 13 Climate Action & SDG 14 The Life below Waters

As already analyzed the anthrophonic impact upon ocean ecosystems is steeply increasing, from rising water temperature to ocean acidification and diminishing coral reefs, which are vital for a functioning ocean. The triggered loss in 90% of large fish stock (Dietz et al., 2003) and biodiversity, which endangers human food supply and thus social wellbeing. Seaweed emerges as great regenerative intervention by **substituting the diminishing coral reef**. A 71000 km^2 kelp farm in Australia was cultivated to substitute the declining great reef and supported biodiversity, fishing and tourism with an estimated value of US$7.7 billion annually (Bennett et al., 2015b; Buschmann et al., 2017).

Not only does seaweed **support biodiversity** of other marine species, but it also carries high functional and response diversity towards climate change as it sinks in CO2 (Duarte et al. 2017; Froehlich et al. 2019; van den Burg, 2019). Marine plants, especially seaweed has been estimated to cover 3% of ocean surface and sequester 70% of the global CO2 (Chung et al., 2011), producing 54% of global oxygen. Seaweed triumphs terrestrial **carbon sink** solutions like trees as every wet metric ton of seaweed can sequester 100kg carbon sequesters, and is one of the fastest growing plant (60cm per day), being more efficient in carbon offsetting than terrestrial solution e.g. forests (Bloomberg, 2020). The brown alga Ecklonia sp., is estimated to sequester 10 tons of CO2 ha-1 yr-1 (Barbier et al., 2019). Current seaweeds, if not harvested for human use, but solely used for offsetting, could already take 2 million tonnes of CO2, which translates into 1.11 thousand tonnes of CO2eq per year per square kilometer (Seaweed for Europe, 2020). Tim Flannery (2019) envisions the radical idea to sink seaweed into deep ocean as long-term carbon storage. Taking solely 9% of current ocean would enable 50 metric gigatons of carbon to be sequester per year (energy sector is 30 gigatons annually; Bloomberg, 2020).

While sequestering carbon, seaweed also purifies water by **absorbing nutrients like nitrogen**, which led to the label of charismatic carbon (Froehlich et al., 2019). Anthropogenic activities like CO2 emission and chemical water pollution bring nutrient levels out of balance, which has negative impact upon marine species which reduces biodiversity. These sites could benefit from seaweed cultivation e.g. seaweed reduces nutrient rise in eutrophic sites (He et al. 2008). While an excess of nutrients like nitrogen endangers marine and terrestrial species, seaweed indeed benefits from it, taking it in, breaking it down and utilizing it for its fast growth (60cm per day)

(Bloomberg, 2020). Seaweed growth rates increased by 48% (P. palmata) and 61% (S. latissima) close to salmon farms while sequestering up to 12% nitrogen (Capuzzo & McKie, 2016). The World Bank estimated seaweed's nitrogen sink potential as 20 tons nitrogen per km^2, translating into 500 million tons, would offset 10 million tons of nitrogen in ocean, which represents 18% of nitrogen leaked in the ocean (Bjerregaard et al., 2016). Furthermore, 500 million tons of seaweed also sinks in phosphorus to a third of current fertilizer used globally (Bjerregaard et al., 2016). Furthermore, oceans being the key temperature regulator, oceans heat up which leads to global icesheets to melt and water levels to rise (IUCN, 2016). Seaweed could mitigate such by weakening wave energy and by preventing erosions.

3.2 SDG 2 Zero Hunger - Securing Food Supply

As human population is growing exponentially while already currently 850 million people live in hunger (Whiteman et al. 2013), healthy, resilient and continuous supply of food lays in on the ground of social well-being. Within the last 50 years, agricultural productivity has decreased 15% (Wood et al, 2000) due to annual losses of 760 million tons topsoil (Walker & Salt). This does not only endanger human famine but also entails great economic losses estimated at 97 billion EUR (2/3 of cost of human health) (Systemiq & Soil Capital, 2019).

Seaweeds are very nutritious with high level of protein, carbohydrates, vitamins (B12, A, K) and other nutrients (zinc, iron and iodine) (Schubel and Thompson, 2019) and thus may "represent a transformational change in the global food security equation and in the way we view and use the oceans'' (Bjerregaard et al., 2016). The growth rate of e.g. brown kelp exceeds the ones of any terrestrial species and having a shorter lifespan a biomass turnover of 6 to 7 times per year is expected (Reed et al., 2008). 83% of global production of seaweed in 2011 was dedicated towards food production, 15% to animal feed and medicine (Craigie 2011, Ehrhart et al. 2013). If seaweed annual growth increases from 8% to 14%, total global production would be 500 million tons dry seaweed, which would result in an additional 10% calorie and 18% of protein supply by 2050 (Duarte et al, 2007; Bischmann et al., 2017) and thus aid to serve the expected food demand rise of 56% and land crisis (Ranganathan 2018).

Current food production is water intensive, account for 30% of energy consumption (United Nations, 2020) and 24% of global greenhouse gases (Bellarby et al., 2008). Current high-water consumption, land use (leading to deforestation and biodiversity loss), fertilization (degrading the soil and polluting water), and CO_2 emission of agriculture threatens the long-term productivity and resilience of global food supply (United Nations, 2020). Instead, seaweed is a highly regenerative resource, it grows up to 1m per day, and it acts as carbon sink (NOTPLA, 2021). When comparing to conventional land sourced fibers, seaweed saves 250kg of Co2, 3000l of water per ton (NOTPLA, 2021).

Seaweed was connected to decrease climate impact of terrestrial agriculture practices (Eyras et al. 1998; Bernstein et al. 2004) while regenerating its productivity. Seaweed carries higher nutrient level than common terrestrial plants and its energy and microbes were found to support plant growth e.g. corn (Alm et al. 2013). Therefore, seaweed has high potential as fertilization substitute, which are currently nitrogen and phosphorous based and are environmentally polluting. This would make food less toxic and thus generate more healthy and reliable food supply in the future (Mouritsen, 2013).

While saving water needed to produce food, seaweed may also help to offset agricultural emission of methane. Methane is a greenhouse gas with a 25 times higher climate potential than CO2 (Teirstein, 2017). Agricultural cattle, especially cows accounted in the US for 26% of methane emission. Researchers in Australia and Professor Rocky De Nys found when seaweed is used as feed additive (2% of total cow's intake) it decreases the methane emission of cattle up to 99% (Teirstein, 2017; Walter, 2020; Roy, 2019). The Asparagopis seaweed was found to activate enzymes that break the methane down to not be released into the air. Currently cows use 5% of their energy for methane production, this can be now saved and unlocking additional energy for growth (van der Werf, 2018). Thus, the feed energy conversion rate increases, the time until cows reach adequate meat level is drastically shorten to 14 months. Thus, seaweed can be concluded as supportive factor for ensuring responsible food production by reducing agricultural emissions.

3.3 SDG 12 Responsible Production & Consumption

3.3.1 Materials – Packaging

Another sector that leads to one of the highest emissions, pollution and resource consumption during production and consumption is plastics. Plastic production depends on fossils and accounts for 6% of oil consumption (same as aviation industry) which is expected to grow to 15% of global CO2 budget and 20% oil consumption by 2050 (Ellen MacArthur Foundation, 2014). Current research has estimated that 150 million tons of plastic already leaked into the ocean which is expected to increase having more plastic than fish by 2050 (Ellen MacArthur Foundation, 2014). New alternative materials must be found. Seaweed species, Laminaria digitata, can be utilized for the production of alginate, as feedstock for bio-packaging segments (Europe for Seaweed, 2020; Israel21c, 2019). Seaweed based plastic, polyeserts Polyhydroxyalkanoates (PHA) was tested to biodegrade in seawater after 6 months (Europe for Seaweed, 2020). This would decrease the oil consumption, substitute the land and water use of current second generational feedstock for biobased plastic e.g. corn and aid the biodegradability and reduce significantly waste.

3.3.2 Clean Energy

Energy demand is expected to increase significantly (Ellen MacArthur Foundation, 2014). Seaweed as organic feedstock for bio-based fuel and energy production would counter the emission created and other climate impact (Hughes et al. 2012; Kerrison et al. 2015). Through microbial anaerobic digestion one can produce methane from seaweed and through more complex microbial breakdown of carbohydrates ethanol can be produced (Wei et al. 2013). Assuming 500 million tons by 2050 (Bjerregaard et al., 2016). 1.25 billlion megawatt hours may be supplied compared to a total energy demand of 85 billion megawatt-hours of fossil fuel in 2012 (IEA 2014).

3.3.3 Sustainable medicine and cosmetic production

Current medical industry scores high in chemical pollution, CO2 emission and waste production. Current production of medicine often contains toxic chemicals for humans while leaking into waterways and have gravel environmental consequences. Macroalgae with higher levels of calcium, magnesium, iron, iodine, natrium and zinc than terrestrial plants are currently researched and indicate promising for treatment of inflammation, viruses, bacteria and be used as antibiotics and bandages (Perez et al, 2016). Within the cosmetic industry beauty products blended with seaweed are utilized for anti-aging and skin moisture balance restoration (Kim et al, 2018). Pharmaceutical and cosmetic products from seaweed are the ones with highest value currently on the market but need further research to leverage upon this opportunity of European differentiation (Fig.2 & Appendix IIV).

3.4 SDG 6 Decent Work & Economic Growth

Seaweed demonstrates that the regeneration of the environment can indeed fulfill both economic as well as ecological objectives. Ocean restoration practices like seaweed cultivation have been defined as one of the key future markets as its cost-benefit analysis is between 1:2 to 1:10 and is estimated to be worth 250 billion USD (National Geographic, 2020). It was found that in the US 17 jobs can be created per 1 million USD spent, which is higher than in conventional industries like gas and oil (Edwards et al., 2013). Tapping into different markets, the global seaweed sector was worth 11.3 EURO billion in 2018 (Seaweed for Europe, 2020) with a total production of 31.4 million tonnes (FAO 2020) with an annual growth rate of 9% (Bloomberg, 2020).

Especially in Europe the demand has grown, seaweed foods and drinks in Europe grew by a factor of 2.5 between 2011 and 2015 and Europe became the highest importing country with USD 613 million worth in 2016 (FAO, 2019). Due to a general consumer reorientation towards healthy and vegetarian food (annual growth 9.6% by 2025; FAO, 2019) and rising concern for the ocean health, seaweed emerges as the fastest growing sector of aquaculture and is expected to scale exponentially by 12% until 2021 (FAO, 2018; Barbier, et al., 2019; Fortune Business Insights, 2019; FAO, 2020; Grand View Research, 2020; Lloyd's Register Foundation, 2020). By growing to 500 million tons, it could support animal and human protein intake immensely accounting for $28 billion market value by 2050. While seaweed can substitute soy meal for animal feed (550 USD/ton), having long chain omega 3 fatty acid seaweed may substitute fish oil in animal feed (1500 USD/ton), which would allow for $15 billion and 50 million jobs and with seasonal workers amount up to 100 million jobs by 2050 (World Bank Group, 2020).

Taking a focus upon Europe and a shorter time frame, seaweed market could be already worth 9 billion EU by 2030 and could substantially aid the sustainability development and recovery from economic Covid-19 crises. By offering 155 000 jobs, which exceed current entire aquaculture, seaweed sector may aid to replace jobs that have been lost during Covid-19 (Seaweed for Europe, 2020). Furthermore, seaweed can act as alternative income for fishers that face rising debt due to productivity loss of fish stock. By offering fishers an economic diversification opportunity, seaweed will aid the economic stability for coastlines (Elizabeth et al., 2016).

4. Europe as Playing Field for Experimentation

While searching for suitable sites for seaweed cultivation, Theuerkauf et al. (2019) defined Europe's ecological water conditions as well as social and economic factors as high potential site for seaweed aquaculture. It bears opportunities to innovate, current political and investors' activities highlight an active interest in expanding capabilities for marine solutions like seaweed. The European Commission strives for blue carbon solutions and an acceleration of aquaculture with its Blue Growth Strategy. European member states and the European Maritime and Fisheries Fund (EMFF) have set 1.7billion Euro aside for sustainable aquaculture (Schultze, 2016; European Commission, 2017).

European seaweed industry is new and demand is high, thus Europe offers a blank slate to experiment and define, build an ecosystem that from the start integrates socio-ecological to economic objectives. It can be seen as an example on how industries and research need to reorientate in order to "build back better, to 'reset' the economy" (Elizabeth, 2016). Supporting the attainment of many social development goals (SDGs), especially touching upon the fundamental challenge of food supply vs climate change, seaweed ecosystem can act as example case for wider aquaculture and food industry innovation how to restore environment while benefitting from it (Seaweed for Europe, 2020).

However, despite the clear demand within Europe with €554 millions of imports in 2016 (FAO, 2018), Asian countries are leading the market with 99% of seaweed cultivation in 2018 (FAO, 2020). Europe remains highest importer which makes its supply of goods again dependent and vulnerable to global price fluctuations and supply shortages. Europe may create more resilient supply of goods as well as benefit social, health and environmental wellbeing.

5. European Seaweed Solutions - Status Quo & Outlook

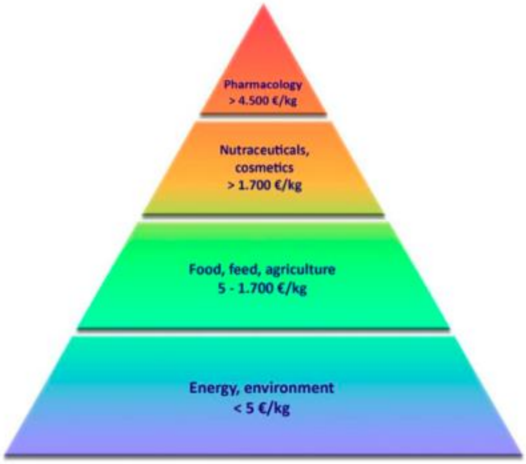
Not only has global market of seaweed gained in speed but also within European borders diverse efforts and startups have emerged. From breeding seeds for edible seaweed in the Netherlands (HortiMari) to farmers in France (Algolesko) to Belgian innovator for offshore cultivation technology (AtSeaNova) and English ventures for bioplastic and food products (OCEANIUM), Europe has key resources and stakeholders available for creating smart business model innovation, collaboration and expanding seaweed market, however these are currently fragmented and disconnect (Appendix XI). Being new to the seaweed market, Europe needs substantial infrastructure building, innovation in technology in order to ensure competitiveness compared to long experienced Asian players (Balina et al., 2017). While water conditions are good (nutrient rich and cold) (Froehlich, Afflerbach, Frazier & Halpern, 2019), Europe currently lacks in experience, knowledge and technology to scale seaweed market appropriately.

Currently, most seaweed harvested in Europe come from wild farms which reach their limits with a stagnant growth of 0.4% CAGR p.a. (FAO, 2019). Whereas the demand for solely fertilization product need is expected to reach 295million Euro worth by the end of 2020 with steep growth projections to overall 60 million tons of demand of seaweed (Seaweed for Europe, 2020). However, ensuring a continuous and high volume of biomass is crucial for seaweed to attain its social, environmental and economic potential. Here cultivation and processing innovations must be found to achieve highest productivity of seaweed production coupled with a maximization on environmental regeneration capability.

The currently low volume of production hinders economies of scale, which translates in a lack of price competitiveness of seaweed biomass and products. Conventional materials like plastic, terrestrial food and bio-based energy sources like corn and soyabeans have a time advantage and thus can leverage upon an infrastructure for low cost. For example, flexible plastic price is around USD 1250 per ton of finished product (Plastic.org 2020), whereas seaweed cultivation already costs 1850 Euro per tonne, which is further increased by later stage processing (van den Burg et al. 2019). Even though seaweed could account for 1.25bn megawatt hours by 2030, current terrestrial biomass sources like corn solely cost 50 Euros per ton (Seaweed for Europe, 2020; Bjerregaard et al., 2016). More research and technological advancement is needed to fully leverage upon economies of scale and to further drive down costs. This will allow European seaweed products of lower commercial value like fuel, food and plastic alternatives to become feasible.

In order to be generally competitive in an Asian dominated market, European players may either go for low prices or aim for high quality of products and thus a differentiation. "The seaweed sector must avoid developing along the old economy's way of cost leadership" (van den Burg et al., 2019, p.1), however current European seaweed market is not very diversified in terms of products, therefore investing and further researching to enter new markets is needed (Mesnildrey et al., 2012). Europe can aim for differentiation with higher margin products (price augmentation strategy) i.e. pharmaceutical and cosmetics (Fig. 2 & Appendix IV) and rely itself on its strength of transparency and quality (Theuerkauf et al., 2019).

Figure 2: Volume/Profit pyramid of seaweed for biotechnology sector (Barbier et al., 2016).



Nevertheless, the expected commercialization and market adaptation of these products is solely within the next 5 years, if not accelerated through additional investment *(Appendix VII, Capuzzo & McKie, 2016)*. In order to scale the industry and move towards making the 2030 vision a reality, the necessary pre-conditions for growth need to be put into place. Although its great climate and economic potential, Seaweed industry in Europe today characterized by a lack of awareness on the benefits, potential and environmental impacts of seaweed on all levels from customer, to politics to entrepreneurs, investors and researchers. This leads to a limiting legal framework for standardization and licensing and a shortage of cost-effective production capacity prevails which combined limits the investment into the industry (Seaweed for Europe, 2020). The lack of market organization and infrastructure capacity makes it hard for off-takers to access large volumes of European seaweed and for farmers to know how much to produce when. This in general hampers a seaweed industry development and an attainment of economic relevance.

Investment must be aimed at knowledge and innovative solutions for production and cultivation as well as product categories must be expanded to make seaweed a competitive alternative solution.

6. System Leadership – Collaboration & Technology Innovations

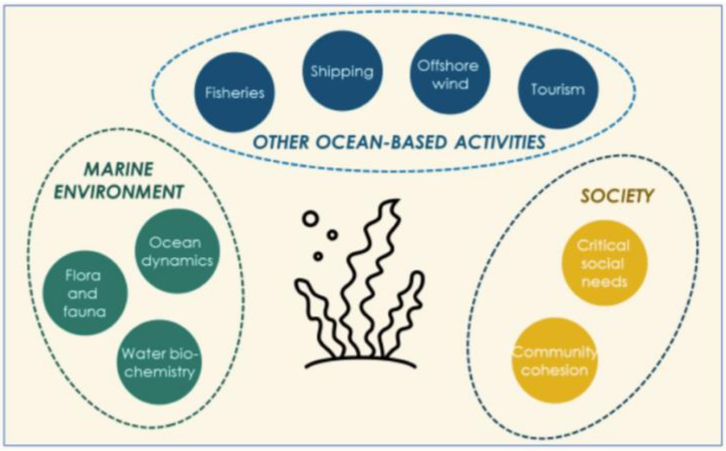
Taking into consideration seaweed's different uses from food to animal feed, bioplastics, pharmaceuticals to biofuels combined with its ecological services like carbon sequestration and habitat creation, seaweed represents a system solution for accelerating sustainable transformation (CEO of Primary Ocean, Bloomberg, 2020). From environmental regeneration to social needs and economic prosperity, seaweed bears a great system intervention for long-term wellbeing (Fig.2)

Fig. 2: *Seaweeds social, ecological and economic Opportunities* (Seaweed for Europe, 2020).

As demonstrated previously, current social, economic and ecological needs are interconnected and within ecosystems, affecting and being affected by the natural systems (Chapin et al., 2009). Corporations act within a web of interconnectedness (Bansal et al., 2017, p.121). The impacts are simultaneously economic, environmental, and social, and "reside at different levels and operate in different logics and time frames and in different spatial scales" (Hahn et al., 2015, p.236). According to Rockström (2009) the biophysical preconditions of human development and current ecological problems are non-linear, interrelated in complexity. This can be also said about seaweed value chain, having various uses (food, pharmaceutical, animal feed, alternative packaging, fertilizer etc.), thus cultivation processes, regulations, prices are non-linear and complex (Seaweed for Europe, 2020).

In order to reach its potential as estimated above seaweed market needs to grow by 14% (Bjerregaard et al., 2016), for which innovations both in terms of managerial strategies as well cultivation technologies for higher efficiency are needed (see SDG 9). Seaweed is part of the ocean ecosystem which entails many species and ecological boundaries like nutrient load, materials which though interlock in complexity to act as a supposedly whole (Bansal & Song, 2017; Senge, 2006; Holling 2001). Therefore, the system cannot be understood by taking its subparts separately. To define the appropriate strategies the market as well as the ecological environment, the ocean, needs to be fully understood, players interdependency defined and environmental aspects fully elaborated. Figure 3. simplified system mapping already demonstrates that the ecosystem cannot be fully understood or built in isolation.

Figure 3 – Socio-ecological-economic system of seaweed (Seaweed for Europe, 2020)



The interconnectedness of seaweed with the marine ecosystem must be considered in ecological as well as economic terms. For sustainable solutions like seaweed to foster companies have to become flexible and resilience focused in order to co-solve interdependent social, economic and environmental challenges. It requires by nature a multi stakeholder approach including ecological research and economic stakeholders, however there is an ideological disconnect to ecological science (Shrivastava, 1994/5) which risks incomplete picture and thus inefficient sustainable interventions (Banerjee, 2003). However, current sustainable aquaculture solutions lack in coordinated initiatives in research, farming and product innovation. This has led to a slow innovation pipeline, lack of investment and market momentum (Seaweed for Europe, 2020). This translates into cost efficiency remaining a key requirement for attaining Europe's potential to scale seaweed market. While facing again the tragedy of the commons, where more regenerative and sustainable solutions are not competitive enough to fulfill demand and thus conventional degrading practices are continued, Dietz et al (2003) highlight the strength of stakeholder self-regulation. Authors determine collaborative action for economic and technological advancement as key driver to leverage upon the full potential of ecosystem services. Collaborative work is needed to generate a price that can compete with Asian seaweed or to enable a product differentiation to argument higher price compared to conventional materials. Indeed, a co-evolution is needed for successful implementation of sustainable solutions like seaweed.

It requires a dialogue and collaboration between different stakeholders in order to consider all risk and opportunities within the complex marine, economic and social ecosystem of seaweed. Freudenreich et al. (2019) highlighted the importance of stakeholder integration within business model definition. The study by Michler-Cierluch and Kodeih (2008) demonstrate the importance of considering all interests and values as only then impactful measures can be designed. Scanning the current market of seaweed initiatives, one can detect a general trend towards collaboration; the Coalition Seaweed for Europe has combined forces of diverse stakeholders along the seaweed's value chain in order to produce a comprehensive analysis for the market and its challenges. Theories of multistakeholder shared value (Bansal & Song, 2017) display how the revenue and opportunities can be even increased for all stakeholders. Furthermore, cooperation with various stakeholders from science, politics, industry, investor to customers enables access to latest discoveries, opportunities and risks and thus dynamic capabilities of corporations increases (Aragon-Correa & Sharma, 2003).

Realizing the capability of partnership to accelerate successful SDG attainment, the United Nations has added goal 17 which encourages cross sectoral multi-stakeholder partnerships. By creating platforms to share knowledge, experience, financial means and technological innovations, the United Nations defines collaboration as key sustainable driver. National Geography and the WYSS Campaign for Nature (2020) also highlight the advantage of partnerships for firms to stay at pulse of the market and to gain access to cross sectoral innovations and revenue streams.
It is a co-evolution of science and business having to quickly scale seaweed efficiency up while respecting planetary boundaries and reach economic competitiveness simultaneously. There is more research needed while having to quickly scale up sustainable solutions like seaweed to significantly help support of 3 billion additional people and mitigate climate change by 2050.

Research Design & Methodology

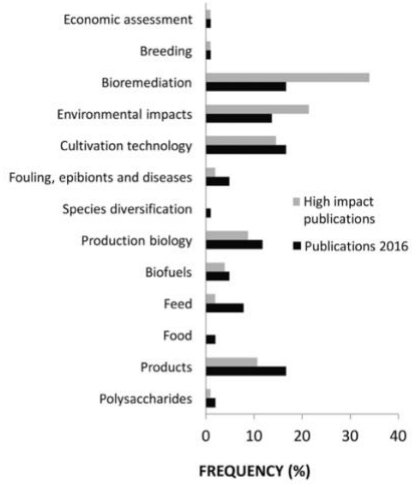
1. Problem Definition

„Devising effective governance systems is akin to a coevolutionary race. A set of rules crafted to fit one set of socioecological conditions can erode as social, economic, and technological developments increase the potential for human damage to ecosystems and even to the biosphere itself" (Dietz et al, 2013, p.1907-08)

Even though we start to integrate the environment, the impact as well as the interventions are very single minded and separately planned. This hinders synergies. We need to create a common ground for productive and impactful communication and pooling resource for strengthening any sustainable and generally new solution. Comparing the increasing corporate sustainability effort and the number of environmental crisis, current sustainable business solutions do not seem to be an appropriate match. They appear to be incomplete, not grasping the whole ecosystem (Whiteman et al., 2013). According to Ehrenfeld (2011, p. 618) "place, role, and practices of business are no longer capable of producing what is wanted without unintended consequences that more than negate the positive outcomes" (quoted in Bansal & Song, 2017).

The underlying problem of insufficient sustainable strategies is the ideological disconnect between ecological science and practical business examples. Current research into economic characteristics of seaweed is rather underexplored, while having a high potential in impact, fundamental understanding among scholars and business practitioners lack in concrete system innovation and leadership recommendations and tools. When analyzing top 100 cited and 100 most recent seaweed research papers in 2016, Buschmann et al (2016) found that economic assessment is underexplored while ecological research is the most common (Fig 3).

Figure 3*: Research tendencies in seaweed (Buschmann et al, 2016)*



A disconnect of ecological to managerial research field appears, ecological study of bioremediation is high but the economic assessment and production biology vital for scaling seaweed is limited (Fig. 3). This leads to a lack of business solutions and technology to transform seaweed into a economically competitive market solution. As the CEO of Primary Ocean defined this challenge as closing the "mitchmatch: market compounds to make it a profitable equation" (Bloomberg, 2020). Thus, limited economic competitiveness of seaweed products towards conventional feedstock as well as Asian seaweed-based product find their root in the disconnect between ecological research and the capital market. There is more research needed while having to quickly scale up sustainable solutions. The lack of exploration of technology and cross-industry collaboration and synergies hinders price competitiveness of sustainable solutions towards traditional materials, food and non-domestic products.

The contemporary challenge for researchers and businesses is to adopt a system perspective to enable a holistic understanding and thus management. However, system thinking for dynamic socio-ecological relationships remains disconnected from core management research (Bansal & Song, 2017). It lacks in consensus in research methodology, conceptual frameworks and practical examples (Whiteman et al., 2013; Gray, 2010; Hoffman, 2011). "The promise of infusing management theory with biophysical foundations remains largely unrealized" (p. 8, Starik & Kanashiro, 2013; cited in Winn & Pogutz, 2013). Instead, a single level focus, silo thinking and reductivism prevails (Whiteman et al, 2013). System thinking requires collaboration, integration of science (Whiteman et al., 2013) and a general understanding that "Managers are not confronted with problems that are independent of each other, but with dynamic situations that consist of complex systems of changing problems that interact with each other" *(*Ackoff, 1979; quoted in Meadows, 2009). Nevertheless, transparency and cooperation however have long been perceived to be risky in terms of idea stealing and revenue decrease and business practices have continued to compete on price and kept trade secrecy all for the sake of market share. Scaling sustainable solutions like seaweed must however create a new economy instead of following the old business models of cost leadership and competition (van den Burg et al., 2019).

2. Aim of Thesis

*"System leadership can change the world" (*Dreier et al., 2019)

Halley Froehlich at University of California concludes that seaweed "provide invaluable new tool for a more sustainable future" (cited in Bloomberg, 2020). The challenges that the seaweed value creation faces are comparable to other new sustainable solutions, thus this thesis' analysis and recommendations towards technology solutions and managerial strategic approaches for system leadership may serve as paradigm for holistic transformation (SYSTEMIQ & Club of Rome, 2020).

Seaweeds demonstrates the capability to act as guiding framework for a new era within managerial practices, *collaboration and co-creation of markets towards while having to speed up ecological research for ensuring long term success*. Therefore, this thesis aims to support closing the gap between ecological and managerial studies by combining both streams within literature review as well as selection of expert interviews. The interdisciplinary literature and interview insights will aim to create a more holistic system understanding of seaweed potential, challenges and solutions. This thesis aims to expand current literature by connecting managerial conceptual frameworks to an ecological analysis of seaweed, thus act as trigger for later research.s

Expert interviews and practical examples will expand and add value to theory (Starik & Kanashiro, 2013). As for the last 25 years system theory has stayed disconnected and thus not explored enough (Bansal & Song, 2017), this thesis aims to create a better understanding, connecting managerial research and ecology along the example of seaweed's value chain.

Most recent conceptual frameworks will be analyzed and applied to management within the seaweed market and further elaborated with expert interviews. This will aid to overcome current disconnect of literature and lack of practical examples. Emerging theories and frameworks from interviews for system leadership e.g. *resilience thinking, learning theory, paradox thinking* will be analysed to support seaweed to overcome current hindrances to scale.
Seaweed market in Europe is new and thus leaves room for experimentation. Therefore, European seaweed may serve as focal market of this thesis, aiming to create an example case for other system solutions. The analysis is aimed to give current decision makers, investors, managers and entrepreneurs a summarizing piece of seaweeds position and impact in the complex ecosystem and how to best leverage upon its benefits, with latest expert insights.

3. Research Question

Facing a degradation of ocean's ecosystem services, there is a need of busines reorientation and co-evolution with science towards system leadership. This thesis aims to generate deeper insights into potential of seaweed to mitigate climate change and ensure social wellbeing and managerial frameworks and technological innovations may aid to accelerate economic competitiveness within planetary boundaries. Expanding current literature and triggered by the fundamental questions raised by Winn and Pogutz (2013, p.21), the research questions will focus on:

What system based managerial strategies are emerging to address ecosystem service resilience decline?

- What managerial strategy innovations and technologies are available for accelerating sustainable system solutions like seaweed within planetary boundaries?
- What business models, competencies and dynamic capabilities lead to successful and effective seaweed ecosystem leadership?

The research question requires multiple areas of research, ecology, technology and corporate sustainable management. Therefore, understanding the capabilities needed for a successful system leadership is key while also analyzing the ecological requirements and possible indirect effects of seaweed cultivation and processing, the planetary boundaries of these strategies will be defined. Any strategy proposed will thus be more scientifically informed and more long-term focused. This lays the ground for the evaluation whether corporate goals can be synched with ecosystem theory and thus whether there is an interest of applying system management frameworks.

4. Research Design

4.1 Mixed Method Approach & Abductive Research

The industry as well as the business models in quest are relatively new and are yet to be explored. Adaptive to this nature and in order to grasp all opportunities and perspectives within this blue economy, the leading methodological approach will be a combination of quantitative and qualitative secondary and primary research. This Mix Method Approach enables to grasp the depth of knowledge and insights it requires to build a system perspective (Modell, 2010).

This triangulation will enable a holistic perspective and understanding of the challenges and opportunities of system leadership for sustainable business model innovations.
Sustainable business research has remained until now a distinctive stream of research and generally disconnected to ecological research. By leveraging upon different data sources this thesis may expand current literature through an encouragement of exchange of information and ideas between management and ecological field.

Especially in qualitative research with multiple sources of information, it is vital to demonstrate transparency for a construct reliability. Only then may there be practical implication insights be created and this thesis may serve as foundation for future research. There is general skepticism whether qualitative data can be reliable and is vulnerable to researcher influence. In order to avoid confusion of the reader through constant switching between data sources and to ensure an objective analysis, a transparent data strategy was created. It leverages both emerging terms from interviews, informant centric data, and higher-level codes and themes from latest management journals, ecological research, which represents the research centric data stream. This does not only broaden the range of aspects the research can consider (Gibbert et al., 2008), it enables an analysis of the connectivity and identification of trends leading to higher information quality (Gioia et al., 2012, p. 17).

First, the researcher conducted general literature review regarding the seaweed market and associated socio-ecological systems. This enabled a basis understanding and system perspective from cultivation to technological solutions to demand stimulating product innovations. These were used to build the value chain of seaweed ecosystem, which serve as basis for later stage data analysis and enables both reader and research to follow and thus reconstruct a system map. The literature review was extended by articles recommended by interviewees which enabled an enrichment of the preliminary research. The literature review acted as basis for the interview questions to create the highest insight and impactful information.

Furthermore, as the researcher faces limited time for conducting this thesis, applying the mixed method approach, researcher continuously combines theory and practical informant insights, going back and forth in order to create a more complete and systemic understanding. Interview quotes and literature themes will be matched to detect linkages, synergies between the previously found ecological data to emerging system based corporate strategies.

Defining seaweed ecosystems as complex, nonlinear and ever changing, the most beneficial approach is abductive research (Folger and Stein, 2017). Abductive research switches continuously between different kind of data, evidence and logics, which may enable a deeper understanding into the dynamics within the ecosystem. Furthermore, having a relatively new stream of research and practice as focus, abductive research allows flexibility and continuous learning during this thesis (Dubois & Gadde, 2002). By allowing a continuous switching between research streams and types, the abductive supports this thesis in expanding current literature with an interdisciplinary analysis. Along the abductive approach, a systematic combination will be applied to expand current literature. Current theories can be compared, tested with scientific expert insights and matched with a practical market case, European seaweed market.

Therefore, the study will leverage upon two different approaches and streams of research, secondary literature desk research and field study interviews as well as ecological and managerial research streams. The interdisciplinary approach will further enable the thesis to increase its natural validity as it strives for system understanding the seaweed market and its role in the overarching ecosystems, ocean, food and material web. Current theories can be tested in their feasibility for sustainable business model innovations an understanding of challenges as well solutions may emerge (Bansal & Song, 2017).

4.2 Quantitative and qualitative secondary literature

Seaweed being new blue ocean opportunity, the knowledge and experience here is very limited. For the researcher to build a basis understanding of both ecological, social and economic systems connected to seaweed, literature and sustainability reports and scientific journals were studied beforehand. This enabled the researcher to understand the current state of infrastructure, technology and demand development of seaweed.

The secondary literature review is sourced globally and was aimed at ecosystem services and the seaweed market. Keywords used for research were: ecological services, seaweed, kelp farms, ocean management and ocean regenerative innovations. This will act as starting point for identify the appropriate stakeholders along the seaweed value chain and will aid the researcher to design an impactful field research and later on build system based corporate strategies (see *Findings*). Due to time constraint while facing such blue ocean solution, insights from interviews acted as trigger for further in-depth literature review of emerging corporate sustainable theories, which are then combined with the scientific analyses of marine and seaweed ecosystems. This enables a definition of the ecological prerequisites of any proposed strategies. Only with this fundament the appropriate technologies can be identified.

For this stream of the research, the following multiple data sources have been utilized in order to represent different valuable social, ecological and economic opportunities, needs and solutions appropriately:

Table 1: Secondary Data stream (Own elaboration)

Datay Type	***Details***	***Use in the Analysis***
Scientific Research, Journals & Institutes	GeoHealth, Science, World Resources Institute, United Nations University (INWEH) and Scottish Association for Marine Science Policy Brief, Oxford Handbook of Business and the Natural Environment, Meridian Institute, MIT Sloan Business Review, Cambridge University Press, ICES Journal of Marine Science	To define current status of marine and seaweed ecosystem as well as challenges and opportunities. Furthermore, emerging system-based strategies in managerial research was used to understand possible intervention points.
Sustainable Coalitions/Initiatives	World Business Council for Sustainable Development, Seaweed for Europe Coalition, World Economic Forum	Understand and trace activities of business initiatives, alliances and coalitions
Sustainability Reports by strategic consultancies	Seaweed Revolution (Lloyds & UN Global Compact, 2020), Bloomberg New Energy Finance (BNEF), World Bank Group	General trend of market and orientations, thus investors requirements to leverage upon emerging opportunities
Organization websites	The websites of organizations of each interviewee	Understand current strategies and stakeholder position and importance within seaweed value chain
Press releases of political players	Politico, European Commission website	Overall sustainable strategy and legitimacy among political levels within Europe

Knowledge Platforms	Ubuntoo	To analyze most recent initiatives to accelerate information exchange and self-regulative market forces

4.3 Qualitative primary data - Interview Sample

Qualitative interviews will be held with market experts to gain deeper understanding upon stakeholders perspectives what innovations are needed to counteract degradation of ecosystem services and to accelerate market development.

The interviews will be with a diverse stakeholder sample along the seaweed value chain. Grounded in open-ended questions, this research approach allows fundamental concepts, rationales of interviewees to emerge by asking for past and current experiences. The interviews are held with various stakeholders along the seaweed value chain, from entrepreneur, investors, farmers, buyers, strategic consultants as well as managerial and ecological academia and technology provider to create a holistic perspective upon the viability of theoretical frameworks. Also, terrestrial agriculture experts will be included. This will enable a holistic understanding of the bigger context of seaweed and enable learning from current food cultivation practices. 16 interviews were held between 30-60 minutes interviews with the following stakeholder:

Table 2: Interview Sample (Own elaboration)

Company	**Type of Organization**	**Type of stakeholder**	**Date of interview**
A	Sustainability Council & Initiative	Program Manager	10.12.2020
B	Ocean Funding Initiative	Ecological Research & CCO	18.02.2021
C	Ocean Initiative	Business Development Manager	06.02.2021
D	Seaweed Coalition	Lead & Co-founder	28.12.2020
D	Seaweed Coalition	Strategic consultant for systemic sustainable transformation	04.10.2020

D & E	Sustainability Consulting Company	Consultant & System modelling for Seaweed Coalition	09.11.2020
F	Management & Innovation consulting company	CEO & Founder	20.01.2021
G	Sustainability Consulting Company	Strategic consultant for systemic sustainable transformation	17.01.2021
H	Seaweed Cultivator & Processor for animal feed	Co-Founder	04.10.2020
I	Seaweed Processor for Animal feed	Vice President	15.10.2020
J	University	Sustainability Business Research	13.12.2020
K	University	Zoology Research Scholar	19.12.2020
L	University	Sustainability Research Scholar	22.12.2020
M	Environmental assessment technology provider	CEO & Founder	05.01.2021
M	Environmental assessment technology provider	CEO & Founder	05.01.2021
N	Organic based medicine	Agriculture biology researcher	04.02.2021

4.4 Interview - Data Collection

The other fundamental data collection is semi-structured interviews, therefore it is vital to create transparency for both interviewee and reader. An interview protocol (Appendix XI) was established to transparently demonstrate the topics and questions and the accuracy in information collection. Very impactful here is to have open ended questions and avoid any kind of witness leading behavior or questions. Along the grounded theory (Gioia et al., 2012) this sample of questions is the guiding basis for themes. But are o open to modification if such creates higher value added during the conversation, as depicted in the interview summaries (Appendix XII).

Generally, the questions were categorized into different insight sections and followed a chronological order. From first understanding the initial perspective upon seaweed and role of the participant and thus possible bias. This is vital in order to grasp the underlying understanding and mindset, which lay grounds of a holistic leadership. The strategies and visons impact other stakeholders and the environment. In corporate sustainability two extremes are combines, quantitative profit focus to qualitative socio-ecological wellbeing (Bansal & Song, 2017). Therefore, the informant's perception of seaweed and its potential will be taken as introduction, after which the interview moves on to understanding what is currently challenging a successful scaling of seaweed, what difficulties the informant experience or is aware of.

Argent (2009) laid the ground for question for clear definition of desirable states, objectives, ecologically, economically and socially. Here the definition of needs was aimed up- and downstream of the value chain. From data gathering to monitoring. From whether seaweed is taken to reduce environmental impact and to regenerate ecosystems resilience or rather as biomass for products for human consumption. After a throughout analysis of the market and marine ecosystem needs, the research steers the questions towards possible investment and intervention opportunities to mitigate the challenges seaweed stakeholders are facing. Through understanding the informant's tendency to perceive seaweed's most likely use, appropriate strategies could be introduced and analyzed. Interviewees were are for their current needs and then what investment and interventions they would envision here.

The interview approach was aiming for knowledge co-production, therefore the questions were adapted to the stakeholder's field of expertise to enable themes to emerge throughout the interview. While adapting some questions, a consistency was maintained to allow for possible themes to emerge**.** Semi structure interview with open questions was the technique employed in order to leave the adequate flexibility for grasping perspectives, values and understanding of each interviewee. This enabled the researcher to grasp possible literature gaps and identify additional aspects to consider. This also enables a creation of more practical insights, information rich data, to be implemented within the next years. Qualitative and semi structure interviews is the most common and adequate research when facing a relative new topic in order to leave room for topics and themes to emerge naturally (Bansal & Song 2017, p.110). It enables critical thinking and insights (Bansal et al., 2018, p. 1190).

Furthermore, defining knowledge co-production between entrepreneurs, scientists, managers and technology provider in form of coalitions or other collaboration initiative as key lever for information quality and strategies' impact, the interviewees were asked to share their experience and perception of these to succeed. Set of questions included inquiries about possible benefits, challenges and tools to ease communication between different stakeholders and create a successful system leadership map through triangulation of information sources. Following the approach of Senge et al. (2015), community action research aiming for a coproduction of knowledge, this research approach resembles and demonstrates the natural dynamics within the markets.

The interviews were conducted in English and lasted between 30-60 minutes. Aiming for consistency and transparency an interview protocol was completed in combination with recording and summarizing the interviews (Appendix XII).

5. Research Worldviews

It must be acknowledged that this thesis will mainly focus upon European market data and interviewees due to researcher's access to contacts as well as location. While acknowledging that a mainly European interview sample may limit the validity of strategies proposed globally, the general managerial studies e.g. system and resilience thinking and case studies sourced are internationally applicable and diverse. This may still allow to arrive at general insights while Europe acts as an example for a managerial paradigm shift (Seaweed for Europe, 2020).

Seaweed may represent one of sustainable system solutions to connect industries and scientific research fields, act as a start for the much-needed triangulation of the three different worldviews rationalism, naturalism and humanism. A successful scaling of seaweed potential and long-term impact needs the different strategic perspectives in balance. While rationalism enables resource efficiency and thus competitive, it does not control general industry scale and future environmental impact. Naturalism ensures industry and sourcing remain within regeneration capacity of nature (Gibbert et al., 2008). Furthermore, the humanistic strive to be part of a healthy community triggers the fundamental motivation to transform and adapt current business practices. These are complementary and needed for holistic system solutions, thus this thesis will aim for a switching between these perspectives in order to reach more valid insights (Senge et al., 2007). Furthermore, by taking different world views this thesis strives to raise interest from various stakeholders to further explore systemic approach to sustainable development.

6. Construct Validity

In qualitative research and analysis, construct validity is of importance to deliver reliable results and practical implication (Dezin and Lincoln, 1994) rather than subjective evaluation impacted by researcher's preconceptions. Therefore, the progress from primary and secondary evidence to emerging trends and findings was clearly documented and followed in order to allow reader to understand the connection to research question, construction, methodology to result discussion (Gibbert et al., 2008). Construct validity is maintained by a continuous transparency of procedure, detailed description of findings and how the researcher arrived to the interpretations of the interviews' raw data. Furthermore, the use of multiple sources of insights, transparently and further elaborating interview insights by evidence from literature aid the general reader's understanding of research methodology from raw data to theoretical interpretations (Bansal & Corley, 2011).

7. Coding Process

A coding process of data based on grounded theory was used (Glaser, 1992). This avoids researcher's preconceptions to impact results and enables an inductive data sourcing, which is highly valuable when creating knowledge in new fields like seaweed. Open coding of the different data streams, primary and secondary, enables common informant centric insights to emerge. These serve as a 2nd order coding basis. Seaweed specific problems and solutions focused literature was integrated with informant's answers to complete the insights and derive a system understanding. Comparing these for similarities and difference, the appropriate fit of codes is checked. Furthermore, continuous comparison enabled a summarizing of common codes from 29 to 16 second order codes (Bradley et al., 2007).

This continuous switching and comparing of data also allow for new and higher codes to emerge as well as to reflect the grounds e.g., interviewee's perspectives (Glaser and Strauss, 1967).

Common themes, perspectives and strategy recommendations were detected and categorized accordingly. Eight 1st order codes were detected, which summarized and categorizes second order technical strategies and insights into codes directed towards the research questions (Blaikie, 1993). From these, four common themes emerged, which indentify the underlying force of these codes upon scaling a seaweed market e.g. drivers, challenges and facilitators.
In general, the coding followed an iterative structure, going back and forth between interview transcripts and experimenting theme groups. This entailed continuous adapting of codes, which follows the abductive research approach elaborated above.

This combination of level of data and have both informant and research's perspective enriches the insight into the ecosystem and associated market frameworks. The combined data from interviews and secondary literature was utilized to build a system map of the seaweed ecosystem with indication of pain points. Combined with knowledge gained through desk research, these will build a framework which may identify managerial strategies and innovations to address ecosystem service scarcity, viable innovations and competencies that are required for a successful system leadership. These will be mapped along the seaweed value chain and create a system map, which is increasingly used by many research institutions, think thanks to better visualize and thus understand complex problems, especially sustainable development e.g. Standford Change Labs "Human Change for Sustainable Transformation" and Nature Conservancy "Global Situation Analysis" (Kumu, 2021). Furthermore, a map may be an impactful tool for helping researchers, practitioners and investors to better identify scalable solutions and further exploration needs. This will be followed by a discussion of practical implication for a seaweed venture's business model, and action plan for creating a multi-stakeholder business clusters and digital collaboration platform on Ubuntoo.

The following table summarizes the emerging codes and themes:

Table 3 – Emerging codes & themes (Source: own elaboration)

Themes	**1st order Codes**	**2nd order Codes**
Relevance of am European seaweed industry	Social & Economic Benefits	Employment potential
	Biomass Supply	
	Environmental Benefits	Climate change mitigation
		Unrealized Biomass Turnover

Challenges for seaweed ecosystem	Limited Scientific Knowledge	Uncertain environmental impact
	Lack of market infrastructure & organization	Limited economic competitiveness
		Lack of ecosystem services remuneration
		Lack of legal framework
Drivers for seaweed ecosystem	Technology Innovation	Environmental Assessment Drones
		Biorefinery
		Integrate Multi Trophic Aquaculture
	System Leadership	Shared Cost & Value Creation
		Science Based Decision Making
		Cross-sectoral collaboration
Managerial Facilitators	Adaptive Resilience Based Management	Redundancy Thinking
		Paradoxical Thinking
		Learning Journey

As depicted above informants highlights again the relevance and ability of seaweed to mitigate climate change and touched upon the current challenges that they either experience themselves or perceive to be vital to tackle for a successful aquaculture scaling. The mentioned challenges served as basis for further elaboration on possible solutions. Here informants' answers demonstrated robust trends towards specific technologies relevant and hinted towards the great need to further research. Furthermore, a general understanding of the interviewees that seaweed or any other sustainable solution needs a fundamental shift in business model was detected. The main themes that emerged were to focus upon the system of seaweed and associated industries, stakeholders and ecosystems by applying system leadership. Collaboration was also a common answer when asked how to overcome current perceived challenges, pooling resources and sharing knowledge were here the key levers highlighted.

Therefore, the following section will in detail analyze and compare the informant's insights by first identifying current challenges and then following a business model approach to elaborate on the other themes and solutions emerging.

Findings

1. Relevance of a European seaweed industry

The first finding that emerged is confirming previous literature review upon seaweed aquaculture increasing awareness by investors, entrepreneurs, strategic consultants, politic reforms and customers. Interviewees displayed a general understanding of the capability of seaweed to regenerate the ocean, mitigate climate change and provide economic and social benefits. Interviewees agree here that seaweed represents a relevant feedstock for future biomass supply, being high in carbohydrates it has the potential to outgrow by far terrestrial biomass turnover. Furthermore, interviewees hint towards the previously discussed contribution of seaweed towards deacidification of the oceans and nurturing for species, which will aid to mitigate current drastically decreasing fish stocks and thus help to lift current European fishers' rising debt. Furthermore, an interviewee refers to the rising global dependency of supply chains and presents European local production of seaweed as an example to make European economy more independent and thus resilient towards possibly future shocks like Covid-19.

Table 4 – Examples of evidence by interviewees on the relevance of an European seaweed industry

1st order	**2nd order**	**Example of Evidence**
Social & Economic Benefit	Employment Potential	*"Jobs potentials, which is higher than current European aquaculture together. And the opportunity for currently struggling fishers to generate new revenue. Also taking the learning form Covid-19, our current supply chains are very globally dependent and more balanced approach makes us more resilient economically"* (*Sustainability Consultant)*
Biomass Supply		*"The future challenges of biomass. Steering our productions and materials towards bio based solutions for a more sustainable future, biomass becomes the most critical factor. And by no surprise, seaweed emerges as a champion" (Sustainable Business Researcher)*
Environmental Benefit	Climate Change Mitigation	*"There are other environmental benefits like seen in China where current aquaculture removes 6% of nitrogen and 34% of phosphorus draining annually into coastal areas. China has just recently stated that it expects 100% removal of phosphorous by 2026" (Representative of Ocean Initiative & Ecological Researcher)*

		"we could offset greenhouse gases of nearly 1 million Europeans by 2030" (Seaweed Processor, Animal Feed)

(Source: Own Elaboration)

2. Challenges to scale seaweed within Europe

Despite its defined relevance and innovation potential, seaweed industry is facing challenges to scale, which became clear through the interviews. The following detailed analysis combining interview insights and literature review of current challenges and their root causes allows a formation of more impactful strategies and sustainable business model innovations (see section *Discussion*). Generally, interviews shed light upon three emerging themes, the fundamental one being the limited scientific knowledge which leads to lack of market organization and legal framework. These challenges are interdependent and thus analyzed in the following collectively to holistically understand the root causes of the emerging challenges.

2.1 Limited Scientific Knowledge

2.1.1 Unrealized Biomass Turnover

The supply of biomass from seaweed is varies greatly depending on location and time. The availability of nutrients, light, fish and other human ocean activities impacts the efficiency of seaweeds growth and thus biomass turnover (Bell et al., 2015). Here further research is needed as indicated by the majority of the interviewers being the fundamental missing step for future scaling. This is highlighted by the interviewed sustainability seaweed consultant:

"We need to catch up in our knowledge of the potential uses of seaweed and best cultivation. Europe has indeed promising waters but seaweed biomass efficiency is very dependent on the water conditions, sunlight and other factors. We need to accelerate science, invest in research to understand one the benefits and two the risks"

Current seaweed production only amounts to 3 000 tons within Europe, which would need to grow at least to 8 million tons in order to demonstrate economic viability according to the representative of Seaweed Coalition. In order to identify the most cost-effective production and cultivation research is needed. With affordable and suitable technological solutions lacking (e.g. mechanical harvesting technology for non-perennial species, "fit and forget" systems for offshore farming) and technical developments still needing to be proven before being scaled (e.g., farming equipment that can resists gales. bio-refinery processes, etc.) (Seaweed for Europe, 2020) hampers the scaling of seaweed biomass. This leads to general inefficiencies in cultivation as well as later stage processing which hinders aquaculture products like seaweed to compete with the biomass supply with less sustainable terrestrial feedstock. General insights from interviews demonstrates that seaweed being high in carbohydrates is very eligible for biomass feedstock however its current volume of production is far from competing with conventional organic biomass. Terrestrial annual biomass turnover is roughly 16 billion tons whereas seaweed global products amount for 30 million tons (Interviewee, Business Research Scholar).

Table 5 – Examples of evidence by interviewees on Unrealized Biomass Turnover

2nd order	**Example of Evidence**
Unrealized Biomass Turnover	*"For example, seaweed in theory is very suitable for biofuel as 85% is made of water which makes it very eligible for anaerobic digestion for biogas and fermentation for ethanol. Sugar kelp for example has a very high carbohydrate intensity which makes it a good feedstock for ethanol. But we are still not at the required biomass to compete with any of the conventional materials. The input needed is very high" (NGO representative & research scholar)*
	"Currently the fully life cycle of seaweed is not really studied, during process it has massive losses, wasted biomass due to the lack of efficient technology. Animal feed, using all of the biomass is not the most effective in nutrient and protein supply while energy production from seaweed is not resource nor cost effective" *"It offers an alternative biomass source which does not compete for land, water or other resources. But its scale is not comparable to terrestrial crops; I think it is roughly something like below 30 million tones fresh weight of seaweed, in comparison to 16 billion tons from terrestrial source" (Business sustainability research scholar)*
	"upscaling is difficult due to inefficiency of current biomass creation" (Zoology research scholar)
	"To realize our most ambitious scenario, we would need to grow seaweed production in Europe from currently 3 000 tonnes, from mainly wild harvest to 8 million tonnes, mostly farmed seaweed" (Seaweed coalition lead & Sustainability Consultant)

(Source: Own Elaboration)

2.1.2 Uncertain Environmental Impact

"Massive seaweed farms would change the water dynamics, stemming from the grounds it has a bottom up effect, changing currents and possibly creating isolated climate systems. We cannot simply grow without boundaries, we need to check, generate data. (Sustainability Consultant)

Interviewees continuously highlighted the need for more information on the potential environmental impact of seaweed. Not only are the wider impacts upon other marine species unknown but also the cultivation locations, processes and timing are yet to be optimized. Instead of unregulated cultivation and production, current sustainable solutions need to recognize planetary boundaries within their business model and development. Cottier-Cook et al (2016) warns from loss of bio security of stems and the ocean by introducing nonnative species with monocultural practices. Especially, in waters the mixing with wild species and thus a change of the general ocean flora is underexplored and more difficult to control. The authors present a case of a seaweed farm in the Philippines in which farmed experienced a 15% loss in productivity, USD 310 million economic loss within 3 years, due to a focus upon a few species, thus a reduction of biodiversity (Elizabeth, 2016). Barbier et al. (2019) hint here towards a gap between scientific knowledge and practices and encourages a further analysis of water dynamics and seaweed behaviour.

While seaweed protects coastlines from higher water level by breaking waves, it ultimately interferes with the water dynamics and the associated supply of fresh nutrients. While it protects species like oysters and aid their growth, it creates separates ecosystems with other current, nutrient load and also temperature. Interviewees agree that seaweed farmers need to learn from these mistakes, avoid common practices of monoculture which proved to make plants vulnerable towards diseases and thus decrease the biomass turnover even more. This would lead into a reverse effect of scaling seaweed and needs further research in best cultivation practices and biomimicry of ecosystems.

Interviewees raise the questions for the carrying capacity of water for seaweed and Norway has introduced a mandatory monitoring system on each seaweed farm. As previously discussed seaweed cultivation may affect other marine habitat and as well as is affected by various factors like nutrient water load, light and human actions like windfarms and marine transportations.

Table 6 – Examples of evidence by interviewees on Uncertain Environmental Impact

2nd order	Example of Evidence
Environmental Impact	*"The uncertainty in cultivation of seaweed and the risk of plant diseases are one of the most challenging issues known among scholars" (Biological research scholar)*
	"When we introduce monocultural practices to aquaculture for the sake of biomass efficiency, we might risk disease outbreaks, biodiversity loss" (Sustainability Business Researcher)
	"We need to understand the carrying capacity of the ocean for seaweed, the possibility of pathogens, temperature. In general there is a lack of information of the wider spread ecosystem impact, mixing with native species etc." (Zoology research Scholar)
	"research research! From all sites, ecologically, managerial and in combination with the most recent and updated technology. We need to understand our waters, the carrying capacity of such in order to avoid mistakes that we have done on land." (Business research scholar)
	"the requirements such technology needs to fulfill, we need management protocols but also an integrated warning system when conditions change beyond a previously defined threshold, so we have the chance to intervene early enough!" (Sustainability Consultant)

(Source: Own Elaboration)

2.2. Lack of effective & efficient market infrastructure

2.2.1 Limited Economic Competitiveness

As common to new ecological market solutions, seaweed has a high price and demand volatility, and its optimum productivity is underexplored. Conventional materials like plastic, terrestrial food and bio-based energy sources like corn and soyabeans have a time advantage and thus infrastructure for low cost. It is simply not competitive in economic terms. Costs are a critical success factor and solely achieved through atomization and technology innovation (Seaweed for Europe, 2020). 99% of farmed seaweed stems from Asian regions, these rely on cheap labor, mainly on low margin food application and having lower environmental standards, which leads to a much cheaper price of Asian seaweed. The food as well as the alternative packaging market for seaweed highlights the competitive force of Asian countries, interviewees report here a market price of down to $100/ tonne.

Furthermore, when looking for a potential for seaweed to become a sustainable source of biomass for biofuel, the price discrepancy is even higher. Therefore, interviewed producers for animal feed can solely aim for additive products as current prices cannot compete with conventional feed. Instead of reaching for the possible 38% market uptake, producer see 10% as more realistic (see XII Interview summary).

The lack of the predictability of cost of seaweed production hinders a reliable profit potential estimation for the creation of market product strategies. It brings about the dilemma common to most sustainable solutions, suppliers need to reduce prices by producing more biomass for which they need long term buyer guarantees. The buyer however needs decent price and volumes guarantees from the supplier (Seaweed for Europe, 2020). Potential buyers go thus for solutions abroad like Asian markets for seaweed. Interviewees here refer again to the Chicken & Egg Problem.

Table 7 – Examples of evidence by interviewees on limited economic competitiveness

2nd order	Example of Evidence
Limited economic competitivenes s	*"Quite frankly we absolutely need to compete on price and quality. Asia is long ahead of us especially when it comes to high commodity products like food and feed. You have prices like 100 USD per tonne, which is Europe far from reaching. It is a race" (Seaweed farmer)*
	"Until now we remain at focusing on seaweed as animal feed additive. This due to the higher cost pressure on general feed biomasses with which seaweed cannot compete (...)" *"current solutions are very low in price and there are too many other available organic solutions. Therefore, we build on the high health quality of these additives for animal feed (...). Furthermore, European products especially in these commodity segments cannot be more than 10% higher than Asian products (...) So summing up obviously, Asia has history and cheap labor but EU may outbalance that my focusing on high quality" (Seaweed processor, Animal Feed)*

(Source: Own Elaboration)

2.2.2 Lack of ecosystem service remuneration

The lack of research and understanding of seaweed's environmental impact is paired with a lack of market mechanisms to incentivize such research. When analyzing the opportunity of seaweed to act as solely climate mitigator e.g. carbon storage, sunk into the deep ocean, the lack of market mechanisms is emerging from interview insights. Interviewees hint towards the fact that current systems do not account for indirect effects of CO_2 e.g. ocean acidification and the associated loss of biodiversity (Whiteman, 2013), which makes current CO_2 irrelevant and too little to incentivize transformational change (EU Emissions Trading System, €31/tonne, European Commission 2020). Seaweed offshore cultivation and sinking of carbon is estimated to be 543$ per metric ton CO_2 (Bjerregaard et al., 2016), which stands in no relation to even the highest CO_2 pricing in Sweden of US $126 (Jonsson et al., 2020). Therefore, there is no appropriate remuneration for seaweed's or other sustainable solutions' ecosystem services, which may help its economic competitiveness.

"Also, currently there are no market mechanisms in place to fully value seaweeds benefits. Like biodiversity impact by offering a nursing habitat for marine species, especially when seeing coral reefs diminishing drastically" (Interviewee, NGO representative & Ecological research scholar)

2.2.3 Lack of legal framework

Despite the previously discussed increasing awareness, interviews have shed light to a still prevailing general lack of legal awareness and framework for aquaculture solutions like seaweed. Although public investment and facilitation in terms of industry development is highly needed in such blue markets in order to create higher certainty for private investors, a general lack of understanding among decision makers was reported. Regions within Europe vary greatly in regulation and standards for general safety requirements and monitoring, which emerges as key challenge to accelerate a seaweed industry scaling (Bell & Witkin, 2020). Homogenous and efficient procedure is needed to facilitate seaweed initiatives'' success and development. Lack of uniform safety standards explained partly by lack of awareness from policy makers on the benefits and true potential of seaweed.

This leads to bureaucratic processes and inadequate standard requirements upon seaweed products and cultivation. This is experienced by interviewed market experts as major risk factor, which hinders their innovation and growth from aquaculture to even new terrestrial agricultural practices. Seaweed cultivation requires a license and seaweed products are due to standards, however due to a lack of understanding of seaweed ecological characteristics and impact other marine practices are used as basis for evaluation. Newly introduced higher environmental evaluation criteria by European Green Deal require higher certainty of environmental impact, which is hard to meet for new sustainable solutions which lack in research data.

Table 8 – Examples of evidence by interviewees on Lack of uniform Standards & Procedure

2nd order	**Example of Evidence**
Lack of legal framework	*"lack of understanding and the inefficiency of current political structures.We are measured against even higher requirements than conventional, nature destroying practices" (Seaweed farmer)*
	"To farm seaweed you need a license. (...)they evaluate you on the wrong criteria like offshore wind, salmon farming which is much more harmful in terms of emission, nutrient leaking etc." (Seaweed Coalition leader & advisor)
	"Currently I feel like sustainable solution do not only face a lack of awareness, investment, market movement and research but also gets higher requirements of biological limits, that is just impossible" (Biological research scholar)

(Source: Own Elaboration)

3. Drivers

3.1 Technology Design for Sustainability

3.1.1 Environmental Assessment Tools - Drones

Interviewees highlight the importance to continuously monitoring the changes within biomass in order to quickly detect possible disease or other system collapse. This will give the chance to intervene quickly. The multi-source assessment emerges through interviewees as challenges as current procedures and technologies struggle to deliver timely and easily interpretable data.

Recent technology development acts as enabler to lift these challenges. Technologies combining spectroscopy-based, imaging-based and remote sensing data for reliable and consistent detection and monitoring systems have emerged (Zhang et al., 2020). The use of hyperspectral cameras for detecting plant diseases for terrestrial practices has increased steeply since 2016 (Zhang et al., 2020). According to interviewees what comes in here as very cost effective technique is to attach these cameras and lasers upon flying vessels, drones.

Until now current research practices give a single point data whereas drones can map continuously, cost effective and does not need extrapolation. A study by Norwegian Institute for Water Research, NIVA, (2018) has demonstrated that drone imagery can increase the data insights by one million times. They give more detailed geometric and radiometric imagery. The most accurate data capturing can be achieved. The interviewed technology provider is current working with a Norwegian research institute in order to integrate drones into aquaculture. Drones are transportation vessel with carrying strength and high precision in flying, it can be automated to perfection in flying to the millimeter. Meanwhile it can carry radars, cameras and other scanning technology. The drones with laser UAV-Photogrammetry and laser scanning connect themselves to the satellites and interoperate the geographical data, drones can operate for continuous check-up for diseases, and general growth phase and volume. This will act as basis for finding more efficient biomass cultivation practices.

Table 9 – Examples of evidence by interviewees on Environmental Assessment Drones

2nd order	**Example of Evidence**
Environmental Assessment Drones	*"Problem here is that current monitoring are very cost intensive and not offering readily available information, it needs first long series of modelling and interpretations" (Sustainability Consultant)*
	"Like for example instead of equipping a boat with scientists, why don't we use satellites, drones which brings the data to us?!" (Business research scholar)
	"Current approaches are time consuming and often information poor, requiring intensive time to model (...) Scanning the environment, help to accelerate the data collection and interpretations" (Technology provider, environmental assessment)
	"I have heard about a project in California using satellites for time and geographical scanning. Flying vessels makes sense for big seaweed farms for low cost monitoring over time. This monitoring might enable to understand the variation in growth, seasonaility, costs etc. (...)" (Zoology Research Scholar)
	"The research and innovation potential of hyperspectral imaging, interpolation with satellite data and thus a multi-source RS pool of information has steeply increased

	in the last years. The integration of the multisource data, a software that makes information readily available. This saves time and costs and increases the researcher's insight." "Here equipped drones can help to deepen the imagery to 29 nanometers. The laser already partly covers the vegetation cycle and the software that we have created to interpretate data is already at 95% accuracy, this has not been achieved by any other monitoring technology" "The data collected, analysed and categorized can help to prevent major crop losses, waste and identify the highest yield point of time. Here is the opportunity for investors to not only scale seaweed but taking it as an example of other sectoral wide application" (Technology provider, environmental assessment)

(Source: Own Elaboration)

3.1.2 Bio Refinery

"Biomass being the key future resource for any material, fuel, food replacement, it is definitely bio refinery in terms of processing that needs further expansion, research to make the extraction of valuable resources more efficient. Like this we can create a closed system, valorize the whole resource, to its smallest parts" (Sustainable Business Consultant & Seaweed coalition advisor)

Interviewees from seaweed cultivating and processing companies for animal feed raise the issue of a lack of technology to extract the most valuable and health related components from seaweed biomass, which would make it more competitive and would help to argument the higher prices. Currently interviewees experience a choice between being cheaper or to generate higher prices. But "investors that we talk to, who are willing to pay a higher price still require a 3:1 Return on Investment "(Sustainable Business research scholar). The key leverage for higher market penetration is costs and to reduce waste byproducts of current production, turn them into high valuable products and revenue streams (Barbier et al., 2019).

Bio refinery emerges as key technology to enable seaweed feasibility and thus scaling from interviews. Biorefinery technology is a mechanism in which different components of seaweed are extracted e.g. proteins, antioxidants, oils for various industrial applications (Ballina et al., 2017) and which can then aid for economic diversification of products. By increasing the stream of revenue and costs driven down through high utilization of bio refinery processes, seaweed products may become more economic competitive and thus attractive for substitution for e.g. food, feed and medical appliances.

Table 10 – Examples of evidence by interviewees on Biorefinery & Cascading Approach

2nd order	Example of Evidence
Biorefinery	*"Bio refinery comes in here quite handy even if it is still at the beginning. With a system that filters high value products while producing lower value products we can add more revenue streams and make thus seaweed products overall more accessible"(Seaweed Processor, animal feed)*
	"So a bio refinery which is simply a system that can extract more from seaweed than we currently use, can create higher value products while producing lower margin biogas or animal feed. This can help these products to compete" (Representative of Ocean Initiative & Ecological Researcher)
	"Biomass being the key future resource for any material, fuel, food replacement, it is definitely bio refinery in terms of processing that needs further expansion" (Business Consultant & System modelling for Seaweed).

(Source: Own Elaboration)

3.1.3 Integrated Multi Trophic Aquaculture

During interviews, collaboration in aquaculture cultivation emerged as viable strategic option for exploring seaweeds impact while reducing costs. Integrated Multi Trophic Aquaculture (IMTA) is the combination of various marine activities from fin fishing to shell cultivation to wind farms. It follows a bio mimicry approach copying natural processes to generate an efficient food chain in which one species feeds on the waste of another which helps to prevent resource depletion. Seaweed is increasingly cultivated along fin fishing in order to offset the increased nutrient water level and to offer species food. For example, in Korea a farm integrates abalone shells, that feed off seaweed and emit organic waste which is used by sea cucumber or other invertebrates (Elizabeth et al., 2016). The seaweed takes in the inorganic waste products from fin fish and shellfish and breaks it down for its growth (Appendix III).

In Canada, a project found that the complementary roles within the water of each species led to less waste product as well as less cloudy water in bays (Government of Canada, 2019). In other project, seaweed growth rates increased by 48% (P. palmata) and 61% (S. latissima) close to salmon farms while sequestering up to 12% nitrogen (Capuzzo & McKie, 2016). This let scholars conclude that IMTA overall mitigates environmental pressures (Feng et al., 2004; Yang et al., 2015; Buschmann et al., 2017).

Table 11 – Examples of evidence by interviewees on Integrated Multi Trophic Aquaculture

2nd Order	**Example of Evidence**
Integrated Multi Trophic Aquaculture	*"There is a company, BIOMAR, that found that feeding finfish with seaweed decreases the mortality of these as it cleans the waters, and less waste is poisoning the fish. This is the whole idea of integrated multi trophic aquaculture, which entails instead of exploiting only on top of the food chain, bigger fishes, we actually nurture the conditions in a bottom-up approach" (Representative of Ocean Initiative & Ecological Researcher)*
	"What I have seen are a combination of salmons, oysters and seaweed. Salmon have a lot of waste, which the oysters biofilter and the seaweed prevents sludge. Oysters for example are very profitable so combining them with seaweed my help to share costs. Also seaweed breaks waves and thus protects the oysters better" *"I would take a step-by-step approach. First phase being when seaweed is a side product while its conditions in different scenarios is researched. You have nothing to lose here, you simply have to integrate it into something that we are already doing"* *"We need to start growing seaweed in order to understand its impact. Thus, I would integrate seaweed into current aquaculture, experience with multi trophic closed systems while monitoring"* *"I think it is difficult to have more than two species: operational side, different customers, different regulation, different quality insurance" (Zoology research Scholar)*

(Source: Own Elaboration)

3.2 System Leadership

3.2.1 Shared Cost and Value Approach

What scientific scholars and interviewees agree upon is the beneficial effect of partnerships in order to rethink systems, infrastructure, decision making, products, enterprises models and investment behavior (Diehl et al, 200). Currently, suppliers of seaweed are fragmented and disconnected which lead to an uncoordinated development and lack of the needed market pull and beneficial infrastructure (Seaweed for Europe, 2020). However, all stakeholders along the value chain of seaweed are needed to enable this co-evolution leveraging upon both top-down and bottom-up approaches. Including the value creation for stakeholders will aid the legitimacy of the strategy and thus the speed of introduction. Sustainability research hints towards three main organizational initiatives that benefits its value (One Ocean Foundation, 2019). The first being the collective creation of standards and certification governance body, the second being dialogue platforms. This increases the certainty and competitiveness of seaweed products. The third lever is defined as the technological assessment of environmental impact, which will be discussed in the following sections.

Cocreating a market infrastructure and mechanisms may help to lift current disproportional allocation of wealth. Current markets are structured to support wealth of the hierarchal higher players but lower level fisher are facing price cuts and productivity losses due to natural resource degradation (Seaweed for Europe, 2020). Thus, when creating an inclusive system this may help social inequality as well as foster understanding, trust and acceptance.
"(…) why for example should someone be incentivized to work towards creating more value if this value only ends up benefiting someone else?" (Interviewee, Sustainable Consultant). Thus proactively by including until now price squeezed stakeholders like farmers it may increase the openness to collaborate and accept new technologies.

Storage, production facilities and technologies need to be found, which are indeed available but not seized due to the lack of cross sectoral dialogue (Seaweed of Europe, 2020). Furthermore, current long transportation needs between cultivators and processors also hampers the profitability. Here a collective coordination of location would aid to share and reduce costs. Major corporations and financial community need to be involved in order to raise their awareness and gain access to higher investments for research and development. Instead of internalizing research, innovation costs and having unutilized storage infrastructure and machinery a collaboration between stakeholders can pool resources and thus enable seaweed industry to seize more technology opportunities. This will enable a more organized market infrastructure and aid the economic competitiveness of seaweed products.

Table 12 – Examples of evidence by interviewees on Shared Cost and Value Approach

2nd Order	**Example of Evidence**

Shared Cost & Value Approach	*"To accelerate the seaweed industry development. We aim for a shared value approach which includes all stakeholders from major corporations to the smallest fishery. Only then can we reach for a common vision and the synergies can be fully leveraged upon" (Business Consultant & Coalition Lead)*
	"On the production side we need to build an infrastructure and reliable supply chain or rather connect current available and even underutilized resources. For example, storage is available but players are not connected, we need cross sectorial collaboration "(Seaweed Business Consultant)
	"We need platforms for stakeholders to meet, discuss and exchange information" "Well basically if you summarize what we have talked about is that we need collaboration on all levels: research, cultivation, processing, advocacy or rather political governance, corporate strategies and customer engagement" (Business Research Scholar)
	"What the Coalition is working on to create a platform for stakeholders to meet, exchange information and help each other out. We want managers to realize that ecosystem management is a continuous learning. We need flexible models that can adapt, be dynamic, flexible, transparent and informed" (Climate Action Manager at corporate sustainability initiative)
	Pooling resources and sharing technologies will allow for shared value and full usage of manpower and available infrastructure" (Climate Action Manager at Corporate Sustainability Initiative)

(Source: Own Elaboration)

3.1.2 Science Based Decision Making

Interviewees emphasize the infancy of research into seaweed's potentials and risks and urge decision makers to first invest in research to understand the ecosystem. According to various participants the success of seaweed scaling depends on a environmentally adapted strategy, for which more data insights are needed. Collaboration and active integration of scientific researchers can help to improve knowledge of decision makers and ensure more resilient strategies. This will also aid to decrease the uncertainty for investors and may lay the basis for increasing market momentum.

Table 13 – Examples of evidence by interviewees on Scientific Based Decision Making

2nd Order	Example of Evidence
Scientific based decision Making	*"Scientific based decision making. First research, I mean we don't know how to best grow seaweed, nor do we know how to best process it and are far from understanding long-term effects on the environment when seaweed is scaled… That is a lot of question marks (..) We need more data for more innovation for scaling" (Sustainability Business Research Scholar)*
	"To start with is science integration into managerial strategies. We need science based and informed decision making. On the forefront here is data generation in order to define the most appropriate locations, where ocean ecosystems benefit the most" (Sustainability consultant)
	"Data is everything, literally the basis of all possible interventions to any challenge. Only through understanding the environment you can be impactful" (Technology provider, environmental assessment tools)

(Source: Own Elaboration)

3.1.3 Cross-sectoral Collaboration

"Understand its multiple use and therefore the definition the stakeholder and all the different markets and sectors relevant to seaweed"(Representative of Ocean Initiative)

Collaboration as key lever for successful system leadership within seaweed ecosystem becomes even more apparent when observing European Commissions latest legislation to Marine Spatial Planning (MSP). As oceans are rising in attention to realize sustainable and social development goals through e.g. renewable energy, carbon storage (Tietenberg & Lewis, 2016) and aquaculture, its space needs to be efficiently planned to avoid future competition and inefficiencies as on land (Elizabeth et al, 2016). Seaweed belongs to a bigger ecosystem, ocean, and thus its strategies need to consider possible future spatial conflicts (Appendix IX). This entails a cross-sectoral dialogue of previously thought independent industries.

Interviewed market experts stress the power and importance for cross sectoral collaboration. They hint towards the opportunity to proactively create partnerships with CO2 intensive industry players e.g. oil refinery and chemical plants in order to create market for seaweed's ecosystem services. This is further elaborated by a European seaweed animal feed processor by hinting towards similarities of technology needs between seaweed drying and terrestrial products like mushrooms and berries.

Table 14 – Examples of evidence by interviewees on Cross-sectoral Collaboration

2nd Order	**Example of Evidence**
Cross-sectoral Collaboration	*"Also very interestingly the technologies that helps seaweed data generation, research, cultivation and processing is also applicable to other organic biomass feedstocks, so plants (...)" (Business Consultant & System modelling for Seaweed).*
	"this technology and data processing apply everywhere, whether terrestrial in agriculture, construction, forestry to aquaculture, from monitoring, scanning to disease and phatogens identification, we need a collaboration. A pooled resource allocation into research and development of technology solutions here is key for the speed of any sustainable market growth" *"We aim to create a multi-functional technology cross different sectors, I see a lot of parallels to forestry and resource management and analysis to seaweed. Synergies are to be taken and worked with!" (Technology provider for environmental assessment)*
	"We have partnered up and located ourselves close to an oil refinery, of which waste heat is used to warm tanks and CO2 emissions are directly put into waters for an accelerated growth of the species as well as carbon sequestrating. It extends the CO2 life cycle (...) It is definitely worth forcing the polluting industries to integrate such interventions and prolong the carbon life cycle. Our vision: 1 Gigafactory of seaweed like the one from Tesla for each oil refinery (...) Also the drying technology is very expensive, here other sectoral partnerships are on our mind e.g. berries & mushrooms cultivators that also need microwave like drying" (Seaweed processor for animal feed)

(Source: Own Elaboration)

4. Managerial Facilitators

4.1 Adaptive Resilience-based Management

„We need a paradigm shift in management, make decision makers understand that they are part of a much broader system and that business model innovations go far beyond conventional boundaries and prerequisites" (Business Development Manager at ocean initiative)

One of the section of the interviews was directed towards appropriate system leadership strategies and needed skills and capabilities for stakeholders along the seaweed value chain. The answers of interviewees shed light upon Adaptive resilience-based management (ARBM) (Kenneth, 2014). ARBM is a holistic system management through all levels of the value chain, expands the access to information through a learning mindset and thus offers more strategic insights and recommendations for ever changing environmental management (Kenneth, 2014).

Underlying mindset of the ARBM is to perceive the continuously adapting and changing nature of the environment as its source of resilience; Accepting temporal what seems to be inefficiencies in order to maintain natural cycles and balances instead of striving for optimized outcomes and efficiency. Emerging form the interviews and confirmed by secondary literature is the importance of resilience understanding both in terms of ecological regeneration and production infrastructure planning. Understanding the interdependence and ever changing environmental conditions being key for natural regeneration, managers within the sustainable markets must leave conventional beliefs of static and stable objectives and KPIs (Whiteman, Walker & Perego, 2013; Carlsson and Bereks 2005). Instead of a one single stable equilibrium, scholars suggest that natural processes have multiple equilibria which allows for ecosystem service persistence even during natural shocks. Resilience is the capability of a system to maintain its functions and ecological services while buffering shocks and general changes (Folke, 2006, p. 259). Managerial strategies are here for example to aim for modular production processes that is expecting shocks and can contract and expand flexibly depending on biomass supply. Learning mindset and redundancy thinking are also powerful tool that will be elaborated next.

Table 15 – Examples of evidence by interviewees on ARBM

2nd order	Example of Evidence
ABRM	*„A fundamental understanding in adaptative management is that the strived objective is also changing and transforming, that there is no single equilibrium but many of optimal stages depending on the surroundings“* *"Adaptive management is also expecting shocks and varieties in harvest and be prepared for such. This can be achieved through modular planning of productions technologies (Climate Action Manager at Corporate Sustainability Initiative)*
	„we must here plan our strategies and sourcing of material in way that does not too much intervene with the natural cycles. We need to be continuously informed about

	the state of crop or seaweed, in order to understand the causes possible, improve productivity and prevent catastrophes" (Agriculture biology scholar)
	„We need a paradigm shift in management, make decision makers understand that they are part of a much broader system and that business model innovations go far beyond conventional boundaries and prerequisites" (Business Development Manager at ocean initiative)

(Source: Own Elaboration)

4.1.1 Paradoxical Thinking

Bringing together different worldviews, interests and values aids the corporate reorientation, innovativeness and learning but also lets paradoxical objectives emerge. Examples named by interviewees and scholars are among others growth vs fast expansion vs slower relationship and pathway dependent development and local efficiency gain vs global ecological impact.

Instead of feeling threatened by contrasting objectives, interviewees see here the innovation potential and the success levers for holistic system management. This is further supported by Hahn et al. (2017) who find that divergent value perspective in corporations can accelerate organization transformation. This comes from the mere realization that current practices are not yet fully matching environmental challenges by focusing solely on the climate issues that can be seamlessly integrated with conventional financial objectives (Whiteman et al., 2013). This follows the paradoxical theory which entails accepting short term possibly conflicting objectives in order to leave room for those to develop in terms of research and strategies.

Table 16 – Examples of evidence by interviewees on Paradoxical Thinking

2nd order	Example of Evidence
Paradoxial Thinking	*"We need to start accepting that there are paradoxical objectives, and that the combination may bear the solution."* *(Representative of seaweed coalition & sustainability consultant)*
	"Now we are facing paradoxical goals. Efficient resource supply vs regenerating the environment. A key skill here is to accept these objectives all, let them be explored for possible synergies and develop eventually. This ensures a general and companywide awareness of the complexity of ecosystems"

	"Tensions and tradeoffs between different interests and objectives are the starting point. In them lies the required complexity and adaptivity of solutions for the complex natural assignments" (Management and Innovation strategy consultant)
	Tensions and tradeoffs between different interests and objectives are the starting point. In them lies the required complexity and adaptivity of solutions for the complex natural assignments.

(Source: Own Elaboration)

4.1.2 Redundancy Thinking

Instead of striving for a stable environmental state, by the 1980s along the development in ecosystem theory, scientific scholars called for a dynamic perspective upon ecological resilience (e.g. Holling, 1986). Ecosystems should be understood as constantly changing and adapting (Mackay et el., 2019) and scholars hint towards the vital role redundancies within nature. Current prevailing management approach strive for efficiency which commonly aims to reduce redundancies. However, scholars as well as interviewees agree here that redundancies within organizational practices as well as natural resources helps to make systems more resilient towards shocks. The climate action manager raised the important messages that while business scholars try to find the best optimum cultivation techniques, there is no single technique that will result in optimal biomass turnover in the long term. The combination of different techniques, from on- near -and offshore all practices should be further explored as it decreases the risks of natural shocks impacting all supply sources equally and simultaneously (Seaweed for Europe, 2020).
Organizations experiencing a steep decline in natural resource productivity e.g. fish and rapid environmental changes which threatens economic competitiveness.

Table 17 – Examples of evidence by interviewees on Redundancy Thinking

2nd order	**Example of Evidence**
Redundancy Thinking	*"For example, through bio mimicking natural ecosystems we can detect that its resilience stems from diversity of sources, location, size. Therefore, opposite to possibly our first intuition, we should keep the redundancies and diversity in supply, farming size, cultivation technique. From small to big farms, on- or offshore, wild harvest, integrated systems etc. There is no silver bullet, the combination makes it diverse and thus more resilient" (Climate Action Manager at Corporate Sustainability Initiative)*

	"we need to be open to new dynamic work streams and factors due to the ocean's nature. Only then can we utilize and expand markets and impact of natural ecosystem solutions. Instead of efficiency we may also need to build redundancies" (Agricultural biology researcher)

(Source: Own Elaboration)

4.1.3 Learning Journey

"Relationship building requires communication skills, strategies, interest and common understanding and vision. Stakeholders need to open up from, all need to be appreciated and included in solutions. (…) sessions need to be scientifically and number based while qualitative and social factors need to be considered and collective learning aimed for"
(Interviewee, Management and Innovation strategy consultant)

The Management and Innovation strategy consultant interviewed highlights the need for stakeholders to learn collectively. The following discussed learning journey proves to be impactful to ensure a learning based management of resources. Interview insights shed light upon the difficulty to create a productive plying field with such diverse stakeholders, thus perspectives while aiming for completely new managerial styles. Paradoxical and redundancy are highlighted as vital levers for corporate sustainability development, however such need to be balanced and adequately managed as having diverse stakeholder together, different and possibly even contrasting needs and interests emerge which may hamper collective strategies.

One of the emerging tool was the learning journey, a combination of learning scenarios from brainstorming to system simulation to on-site visits. The main aim of this learning journey is to combine practical and theoretical insights in order to enrich stakeholder's perspective and understanding for other players' needs. By involving a diverse level of stakeholders from major managers and politicians to farmers, encourage on site visits, the learning journey aims for the stakeholders' realization of the deep interdependency of each player.
Interviewees here advise to communication and understanding.

Table 18 – Examples of evidence by interviewees on Learning Journey

2nd order	Example of Evidence
Learning Journey	*"You must act visionary, master highest communication skills. Besides the general willingness to expand the market, you have different prioritizations, interests on the table. Communication tools are the key to generate a common understanding of the importance of each stakeholder. (...) start from interests, needs, it's a people issue" (Representative of seaweed coalition & sustainability consultant)*
	"We apply the Learning Theory here. Company specific we create a learning experience that brings together internal and external stakeholders together let them realize the value of each and everyone and that only together the best solutions and long-term value can be achieved" *"What really proved to be impactful is the on site visits (...) Afterwards we initiate brainstorming sessions and experience sharing trainings"* *"There must be a mix of tools from coaching to online to networking to simulations. There are simulation learning assignments in which stakeholders build together a system map" (Management and Innovation strategy consultant)*

(Source: Own Elaboration)

Discussion of Findings

In general, findings emerging from the interviews confirmed and expanded current literature. Seaweed value chain characteristics, barriers and innovations can be categorized in "Challenges, Drivers, Facilitators", which will be discussed in the following:

1. Relevance & Challenges of Seaweed

"As Albert Schweizer put it: 'We live in a dangerous time period. Humankind is controlling nature before learning to control ourselves' and to begin this learning we need to understand our impact in a systematic way" (Interviewee, Technology provider for environmental assessment).

In conclusion from interview insights as well literature research, one can conclude that seaweed food and product are solutions that address ecosystem scarcity and helps to regenerate ocean resilience, representing a system solution. Especially Europe represents a great opportunity for experimentation and demonstration how sustainable solutions can also strengthen economic competitiveness and employment. EU is leading in importing value, \$613m in 2016 (FAO, 2019), which it can reverse to 30% market uptake with the right investment, technology and product placing (Seaweed for Europe, 2020).

However, European based seaweed products are far from being competitive towards conventional material prices or seaweed products from Asia. Furthermore, current 8 million tons of production in Europe (Seaweed for Europe, 2020) is not capable of meeting the rising demand for biomass efficiently. Challenges to scale seaweed industry within Europe are complex and interdependent. Returning to the defined problem the interview insights confirm the root causes to be a disconnect between science and management practices, disjointed and untransparent value chain which limits stakeholder integration as well as knowledge sharing. The general lack of managerial research of seaweed also translates into the key challenges of establishing economic competitiveness of seaweed products as well as the mere supply of biomass. "We need to create products where you can justify higher prices, so higher quality. Which still needs to be fully researched. European investors don't have it on the radar, they don't have sufficient data points and insights either" (Sustainability Consultant).

The current underexplored, thus costly and unpredictable cultivation and processing practices hinder scaling which is needed to experiment and thus increase biomass supply to meet European demand. The lack of economic certainty in return hinders investor to move forward with aquaculture as well as the establishment of comprehensive political framework. Interviewees highlight the urgent need for quantifiable and reliable data to generate more momentum on all levels; entrepreneurs for innovations, politics for effective and fast licensing procedures, investors and major corporations for financial resources. However, the general disconnection leaves research struggling to generate data for viable market products, which hinders the economic competitiveness of seaweed products and thus investors' interest. This is referred to as the Chicken & Egg problem by interviewees which defines the need of having a minimum of two players, investors and research, and their cooperation for creating viable products that will drive demand and thus seaweed's markets.

2. Drivers

2.1 Technology Innovation

Another finding that emerged from the interview insight is that the lack of research may bear risks due to the unknown environmental impact. Seaweed and general sustainability advisor refer to this as cognitive debt. This phenomenon is described as the need for research to catch up with current innovations and quickly close the current knowledge gap of wider environmental feedback loops. Interview insights demonstrate a general tendency towards a step-by-step approach in order to reach full sustainability along the value chain, from production to consumption. This needs a holistic analysis of the three levels: planet, profit, people. The sustainability design by Diehl et al (2009) highlights steps to ensure long-term sustainable product innovation. A crucial factor is the **assessment and quantified monitoring** of the real impact from all levels, local, global, environmental, socially and economically and **to follow eco design, mimicry and regeneration of the environmental resilience**.

Currently, the most common utilized research technique still involves researchers on boats taking samples, which is labor intense and thus not cost effective. Furthermore, researchers end up having a lot of data but not very high in information as the dimensions of research remain limited and the interpretation of data manually. This is referred to as Data-rich, information-poor DRIP problem, by interviewees. Here technology is hinted by the interviewees as solutions. Technologies combining spectroscopy-based, imaging-based and remote sensing data for reliable and consistent detection and monitoring systems have emerged (Zhang et al., 2020). The use of hyperspectral cameras for detecting plant diseases for terrestrial practices has increased steeply since 2016 (Zhang et al., 2020). Until now current research practices give a single point data whereas drones can map continuously, cost effective and does not need extrapolation. A study by Norwegian Institute for Water Research, NIVA, (2018) has demonstrated that **drone imagery** can increase the data insights by one million times. They give more detailed geometric and radiometric imagery. The most accurate data capturing can be achieved. This would aid the definition of growth drivers of seaweed, detect early diseases and thus increase cultivation efficiency.

Integrated multi-trophic aquaculture (IMTA) (Appendix III) offers the simultaneous opportunity of increased biomass, further research exploration during cultivation and economic benefits. IMTA is the combination of different aquacultures to bio mimic natural processes and thus to limit impact upon and rather regenerate ecosystem resilience.

Not only have the species benefitted from it in terms of growth productivity but the combination offers fishers an economic diversification (Barbier et al., 2019). Already in terrestrial agriculture, farmers have learned that monoculture makes one vulnerable to shocks e.g. disease, weather, seasonality (Chopin et al., 2010), by integrating different trophic level species, fishers may generate new revenue streams, ensure high productivity and be less vulnerable to external shocks. Furthermore, Buschmann et al. (2017) found that such integrated and collective approach also increases the acceptability and speed of development for seaweed. It also offers an opportunity for research institutes to research interaction between species and the impact of aquaculture even better by having all processes within one bay (Buschmann et al., 2017).

Seaweed has the potential to replace up to 20% of fossil fuel and account for 18% of plant based protein by 2054 (Barbier et al., 2019). However, in order to be a viable alternative for biofuel it requires a major biomass intake while current market conventional material prices of £ 1/kg is not capable of covering seaweeds costs (Pérez-López et al., 2014). Bio refinery however enables a simultaneous production of special products (£5000 /kg pharmaceuticals) and production of biofuel. This may aid to make seaweed-based biofuel or PHA alternatives profitable eventually (Buschmann et al., 2017; Capuzzo & McKie, 2016).

While aiming for a competitiveness of seaweed products, managers have two fundamental strategy options: revenue generation through price argumentation or cost reduction. Market experts recommend a differentiation for European seaweed products i.e. pharmaceutical and cosmetics (Fig. 2 & Appendix IV) (Theuerkauf et al., 2019). Nevertheless, these are not economically efficient in production as well as great biomass is lost during processing seaweed, e.g. carrageenan extraction from *Kappaphycus alvarezii* for human food looses 60-70% biomass. **Bio refinery**, extracting strategically specific components of seaweed, enables a close loop processing and thus minimization of current waste and a valorizing of seaweed products simultaneously. This waste is high in carbohydrates which could be converted with hydrolysis into biofuels (Barbier et al., 2019). Furthermore, liquid currently lost before extracting the carrageenan could act as bio stimulants. A process called bio refinery may transform this supposedly waste into products like bioethanol and biogas (Barbier et al., 2017), thus turn them into high valuable products and additional revenue streams (Barbier et al., 2019). , bio refinery has the potential to become a crucial example of close loop manufacturing (Ballina et al., 2017). It ensures that all possible byproducts are valorized and generate additional profit streams, therefore it offers a multiple benefit.

2.2 System Leadership

"Here the innovation, the transformation goes far beyond the organization and individual. This is an ecosystem model change, the way we perceive our environment, the relationships within and our actions impact. Instead of simply transforming the business model within the organization, we need to establish first a general understanding of the interdependence of different stakeholders"
(Representative of Ocean Initiative)

Seaweed touches upon diverse set of economic activities e.g. tourism and fisheries and it may come in the way spatially with shipping and offshore wind farms (Michler-Cieluch & Kodeih, 2008). Furthermore, being part of a complex food, fauna web of the ocean as well as carrying an essential role in nutrient and CO2 absorption, seaweed cultivation also interferes in the marine environment. This demonstrates that the ecosystem cannot be fully understood or built-in isolation. As Rockström (2009) highlights planetary boundaries and biochemical processes are all interdependent, which requires a multidisciplinary approach (Whiteman et al, 2013). Science based management is key for a long-term success which entails interdisciplinary collaboration (Bansal & Hoffmann, 2011). Current *"(...) market inefficiencies (...) needs cross collaboration, strong and unified voice to overcome" (Business Consultant & Seaweed Coalition Lead).*

The emerging framework is to **share cost and value** in order to expand knowledge, scale up production and reach economic competitiveness. This concept goes beyond direct seaweed stakeholders and proves to be beneficial for other adjacent industries as well as generic technology innovation as elaborated in the following.
IMTA concepts that combines a variety from stakeholders within aquaculture, offer the opportunity to share costs of environmental assessment and monitoring technologies as well as other cultivation equipment (Barbier et al., 2019). Integrating seaweed for example in offshore wind farms would decrease seaweed price by 10% and mussels being lower in maintenance costs would decrease the price even further (van den Burg et al., 2019). Interviewees also hints towards the generic application us of drone imagery and that an investment in such technology may enabler revenue streams and attainment of Europe as technological forefront.
As the biorefinery process has various applications from agriculture to other aquaculture biomass creation, a further development of seaweed bio refinery would produce valuable insights for general sustainable economy (Ballina et al., 2017). The above-mentioned innovations bear benefits, economic diversification opportunities for other market sectors (Elizabeth et al. 2016)

and thus investors may realize more return on investment. R&D in technology could be shared which does not only decrease cost but increase machinery utilization. Furthermore, scholars also detect a higher flexibility and business responsiveness towards market shocks through technology resource sharing (Seaweed for Europe, 2020).

Seaweed's ecosystem services e.g. regenerate nutrient level, temperature, wave strength in specific regions are not yet tradable in economic sense, but aquaculture farmers may utilize them through **cross sectoral collaboration** (Tietenberg & Lewis, 2016). Seaweed can sequester the emitted CO_2 and act as bio filter for water ways in industrial zones. As an interviewed Seaweed Processor highlights this would not only extend the carbon cycle and thus mitigate climate impact but also give current seaweed stakeholders an additional financial and infrastructure resources. An interviewed sustainability consultant and seaweed coalition advisor hinted towards the Ocean Finance Handbook (2020) which demonstrates the strength and flexibility self-regulated voluntary carbon credit markets through partnerships. This lays the ground for a regulatory standard creation which enables industry to buy credits from farmers and thus increases resource access of seaweed stakeholders.

Collaboration emerges as foundation for better market timing, accelerated research and technology innovation and transformational change of managerial strategies and worldviews. Scanning the current market of seaweed initiatives, one can detect a general trend towards collaboration. The knowledge and innovation Program 'ProSeaweed', in which Wageningen University & Research and NSF are partnering with the industry to develop a holistic sustainable seaweed market. Furthermore, the Coalition Seaweed for Europe has combined forces of diverse stakeholders along the seaweed's value chain in order to produce a comprehensive analysis for the market and its challenges.

There is a need for business model innovation, especially for ocean-based solutions (One Ocean Foundation, 2019). According to Amit and Zott (2012) business model innovation concept either aims for a new market, new system structure, new activity or system governance. Seaweed needs and aims for all of these simultaneously. Thus, interviews and literature confirm that system leadership emerges from a collaboration for gaining deeper environmental knowledge and thus enable science-based decision making to achieve highest environmental impact. Furthermore, collaboration also aids a general cost and value sharing and accelerates the scaling and the attainment of market infrastructure, cost effectiveness and thus general economic viability of European seaweed products (Freudenreich et al., 2019). Thus, a stakeholder perspective is needed within sustainable business model in terms of partnerships.

3. Managerial Facilitators

3.1 Adaptive resilience-based management

Interviewees and literature shed light upon adaptive competencies and dynamic capabilities to train for successful system leadership, especially needed during a multistakeholder collaboration e.g. redundancy, paradoxical thinking and learning journey.

Currently prevailing business models lack in understanding of adaptive management and are thus "placing a system in a straitjacket of constancy (which), can cause fragility to evolve" (Holling, 2018). Just like the ocean, management of marine ecosystem and its products needs to be fluid and dynamic in the way they are managed. The first ocean dynamic management approaches showed promising results e.g. 34-82% less space use and higher adaptability to seasonality, water temperature (Maxwell et al., 2015). This further supports the IMTA approach which mimics natural environment and aids to understand the different equilibrium, the drivers of change. This enables more science based recommendations within management strategies. This will enable a higher flexibility of the corporation itself and help to achieve higher long-term economic and ecological resilience while reducing economic uncertainty following the ARBM approach. One of the emerging strategies in order to enhance the economic and production flexibility and to ensure environmental regeneration and resilience, is redundancy theory. Instead of aiming for large and standardized production and cultivation practices e.g. monoculture, experts hint towards benefits of multi diverse approaches for longterm economic as well as natural resilience. This enables also experimentation potential for scientific research. **Redundancy and resilience theory** is not new as already in 1990, Senge and Sterman recommended companies to aim to transform their value chains into more redundant, locally controlled and responsive streams (Senge & Sterman, 1990).

Often social-ecological objectives stand in contrast to financial objectives, at least this the common business perception (Hahn, 2017). Here adaptive management steers for the acceptance and working with **paradoxes** instead of trying to resolve them. Instead ARBM aims to construct higher certainty through various stakeholder integration, thus learning and decreased risks from shared value and cost approach. This is further supported by scholars that highlight the lack of consideration of conventional trade-offs as opportunities for the sake of financial performance (Milne & Gray, 2013; Slawinski & Bansal, 2015) (p.125). This is further supported by Hahn et al. (2017) who find that divergent value perspective in corporations can accelerate organization transformation.

According to Senge et al (2007) “New strategies are the outgrowth of a new world”. The authors define the decision maker’s understanding and assumptions of the world key to transformational change. With collaboration (SDG17) such worldviews may be enriched with new perspectives, insights and information, building a more holistic understanding of the world and ecosystem (Dietz et al., 2003). Senge et al. (2007) also found the risk of the loss of collective intelligence through the divergence of interests and conceptions. In the MIT Sloan Management Review paper, Senge et al (2007) highlights the risks of such collaboration initiatives if not managed properly to leave stakeholders more informed but without any change in action. Interviewees having experienced this phenomenon advise communication tools and learning facilitations. Here, business leadership coach hinted towards tools to foster learning i.e. a **learning journey** that includes data and information sharing through qualitative, quantitative analysis as well as physical onsite visitations to build relationships expand stakeholders’ horizon.

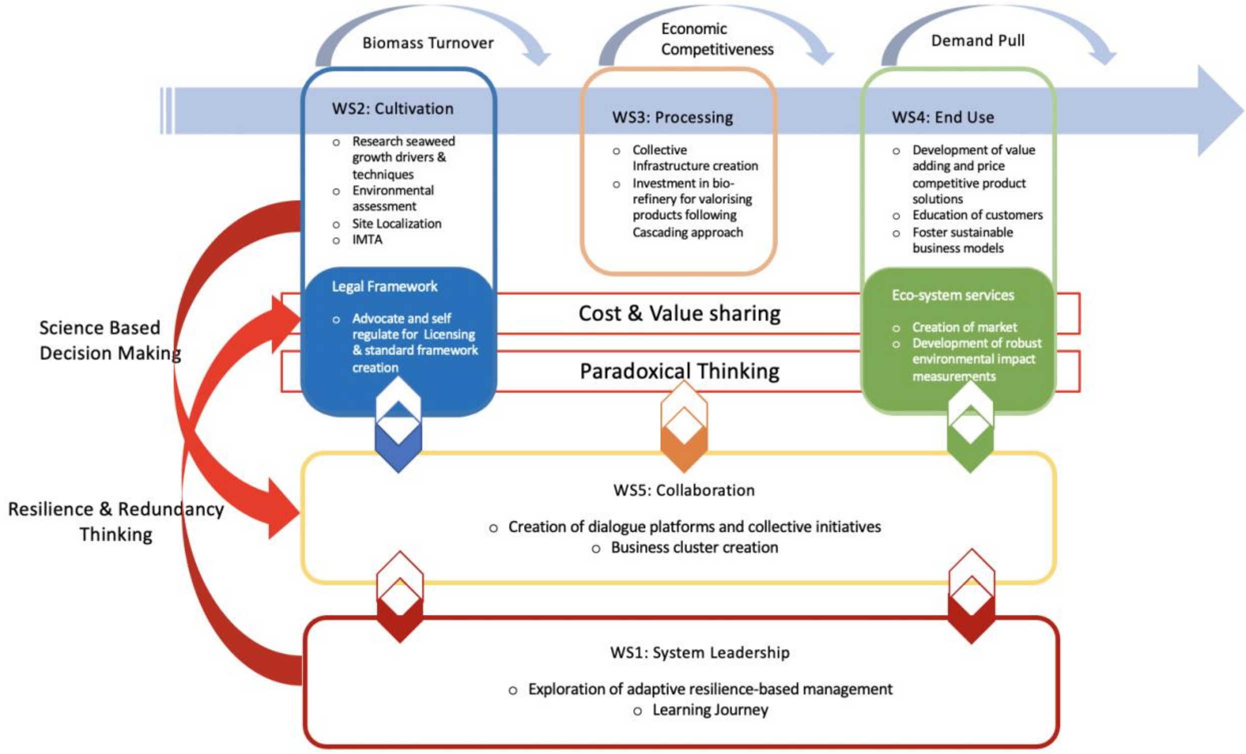
Implications & Recommendations for Industry & Corporations

1. System Leadership for Ecosystem Building

Returning back to the guiding research questions of this paper, this section aims to elaborate how this research contributes to better understanding and practical scaling of the seaweed industry and its opportunities. This research raises the fundamental question of what system based managerial strategies are emerging to address ecosystem service scarcity and loss of ecological resilience. This is further broken down to innovation and technologies that are available for making seaweed solutions more feasible and what business models and competencies are needed to holistic seaweed ecosystem leadership.

The previous deep analysis of challenges, current seaweed development and emerging opportunities can be allocated along seaweed value chain from *cultivation, processing to end use* product and market creation. Innovations implemented at cultivation increase the biomass turnover, measures at processes sing stage aims to increase economic competitiveness of seaweed products which translates in a creation of a demand pull. The additional two, *collaboration & system leadership*, emerge as facilitator of the previous. The emerging investment, research and collaboration activities needed are summarized in the following workstream diagram (Fig. 6).

Figure 7: Seaweed System Map of available workstreams & guiding leadership principles



(Source: Own Elaboration)

<u>Work Stream 1: System Leadership</u>

System leadership builds the fundamental and guiding principles and perspectives needed to ensure seaweed scaling and long-term social and environmental wellbeing (indicated with red frames and arrows). One of the underlying approaches is the creation of resilient aiming and redundant value chains. Designing for sustainability in order to maintain ecosystem resilience follows a bio mimicry approach in cultivation and a science based decision making through collaboration. Shared cost and value approach applies in all three working streams along the value chain, cultivation, processing and end-use. Paradoxical thinking should be followed in order to allow longterm and possibly conflicting objectives to rise which may create synergies. This will also aid stakeholders to work better together. The strategic tool, Learning journey, brings stakeholder closer to each other in terms of understanding needs, interests and creating an inclusive just seaweed infrastructure and business models.

Whereas each initiative and organization requires a different learning journey, scholars have defined 6 general steps to follow (Oracle, 2013). The first being to start with end in mind, understanding what information, capabilities are needed for which objectives. This is followed by 360 degrees of need and market gaps analysis, stakeholders here share their experiences. The third element in the learning journey design is, as mentioned by the interviewees, going beyond conventional learning through written statements, here onsite visits, simulation tools etc. may be leverages. The fourth aspect for a successful learning collaboration experience is to involve also top management, higher decision makers within the ecosystem. These are capable of building the market and legal frameworks for lower-level stakeholders to prosper and fully add to the value chain. The fifth step is to measure results which highlights again the importance of science involvement within the collaboration with which new measurements of seaweed value can be created. The sixth step is to have a robust project action plan and accountability scheme which will ensure stakeholders commitment as well as motivation (Oracle, 2013).

Workstream 2: Cultivation

Within the workstream cultivation, reliable biomass efficiency and cost reductions are the leading objective in order for seaweed to become a viable sustainable substitution for common products. In general, the cultivation design represents a learning opportunity for seaweed stakeholders and other aquaculture markets (Dietz et al. 2003) and collaboration emerges as opportunity to bio mimic natural conditions through Integrated-Multi-Trophic-Aquaculture (IMTA). Drones with attached hyperspectral cameras offer scientific insights for the definition of seaweed growth drivers, environmental impact and definition of most appropriate location for farming sites while lowering time and costs for data generation and interpretation. By combining these with automated software to interpolate all different kinds of data, drones imagery may bear great advancement for seaweed scaling, thus investment and prioritization should be collaboration for collective cultivation and R&D investment for drones.

For efficient cultivation the political legislation must adapt quickly as currently inadequate benchmarks and requirements for system solutions hinders cultivation licensing and thus scaling of seaweed farming. Also monitoring should become a standard to ensure high quality of European products as well as the respecting of planetary boundaries.

Working Stream 2: Processing

The work stream processing aims to increase the economic competitiveness, to reduce price and waste. Bio refinery emerges as key technology to enable seaweed feasibility and thus scaling. As depicted in Appendix X, bio-refinery describes a system of multiple processes from harvesting biomass to thermochemical processing to hydrolyzed and extracted byproducts. A strategic approach towards bio refinery extraction is the cascading approach. The cascading approach follows the logic of producing and extracting the highest value product followed by second most valuable product etc. With this lower margin products like bioenergy are made from byproducts and the quality of the highest value products is focused upon (Ballina et al., 2017). Bio refinery was defined as one of the most promising solutions for the development of new sustainable solutions for food, materials and packaging. Bio-refinery having also applications for other sectors and industries may represent a great investment potential for European players to accelerate transformation for various markets as well as generate additional revenue stream. Furthermore, the current variability of seaweed biomass due to unknown optimum cultivation conditions and changing water dynamics also represents a challenge (Ballina et al., 2017), which needs flexibility and modularity in processing infrastructure, this can be achieved by collaboration and sharing equipment etc for ensuring utilization of resources.

Work Stream 3: End-Use

The end-use work stream is the mere result of the previous steps, which is to create economic competitive and customer relevant products in order to generate a viable demand for seaweed products. This requires further research for new product development and refinement of current products e.g. PHA plastic alternatives, cosmetics and pharmaceuticals. Offering valuable products shall be combined with a general customer education in order to ensure enough uptake. Furthermore, self regulation for creating a market for seaweed's ecosystem services through partnerships should also aimed, which hints towards cross sectoral business clusters elaborated in the following.

Work Stream 4: Collaboration

"A symbiotic trusting relationship between producers, processors and consumer is a core enabler as no part of seaweed value chain can grow significantly without the others" (Kutner, 2014; cited in Seaweed for Europe, 2020, p.33).

Stakeholder self-regulation also has proved to successfully contribute to the competitiveness of European products compared to Asian products. According to interviewees, the key is to play upon local strengths of quality, transparency and environmental and social factors and thus build market standards. These standards eventually become institutionalized and gain official certifications for users to differentiate and augment higher price of European based products.

Certifications are the voluntary evaluation of a products standards e.g. environmental, social. The creation of such certification or eco-labels is already being utilized as competitive advantage by e.g. the food sector, Nespresso and the Rainforest Alliance, to furniture sector, IKEA and the Forest Stewardship Council (Broberg, 2010; Jones, 2017).

Besides commercial products and food, seaweed also offers ecosystem services e.g. carbon sequestering and nitrogen uptake. Nevertheless, current market prices of CO_2 (Europe, 30 Euros/tonne) are not enough to offset current high prices of production. Furthermore, there is no pay mechanisms for nitrogen uptake in the water.

2. Collaboration - Business Cluster Creation

Interviewees and scholars hint towards a need to self-regulate and proactively create markets to trade these in a more impactful way. Interviewees envision one gigafactory per oil refinery plant in which the CO_2 is pumped into the seaweed, prolongs the carbon cycle and helps seaweed to grow.

Business clusters in which stakeholders are brought together to exchange information, share costs and processes of cultivation (IMTA) and extraction, processing (bio refinery) is recommended (Barbier et al. 2019). However, current stakeholders are fragmented which increases transportation costs and energy loss (Barbier et al., 2019) and therefore bio refinery and IMTA are still costly and inefficient. Furthermore, if seaweed biomass per farm is scaled as planned, a steep increase in infrastructure onshore is required, only possible when currently underutilized infrastructure is refurbished (Barbier et al., 2019). This again needs cross sectoral collaboration and coordination. Not only would that be relevant for aquacultural but also for terrestrial products e.g. berries and mushrooms which require the similar drying technology and seaweed stakeholders could thus aim for a sharing of infrastructure, thus costs (Seaweed for Europe, 2020). Seaweed liquid and currently wasted byproducts could be used for fertilization of the terrestrial agriculture of berries etc when bundled in one cluster. Business clusters may localize close to conventional energy intense industries in order to enter collaborations for infrastructure and ecosystem services, prolonging CO_2 cycle. An example of a business cluster is depicted in Figure 8, which displays a collaboration of convention industries e.g. chemical and oil refinery, terrestrial agriculture and aquaculture. The diagram highlights the in- and outflow of activities, revenues and benefits towards seaweed farmers and entrepreneurs.

Figure 8: Business Cluster for Seaweed ecosystem

Source (own Evaluation and copyright of used pictures by Sthankiya, 2019, Kiecksen, 2021 &Chopin et al., 2010)

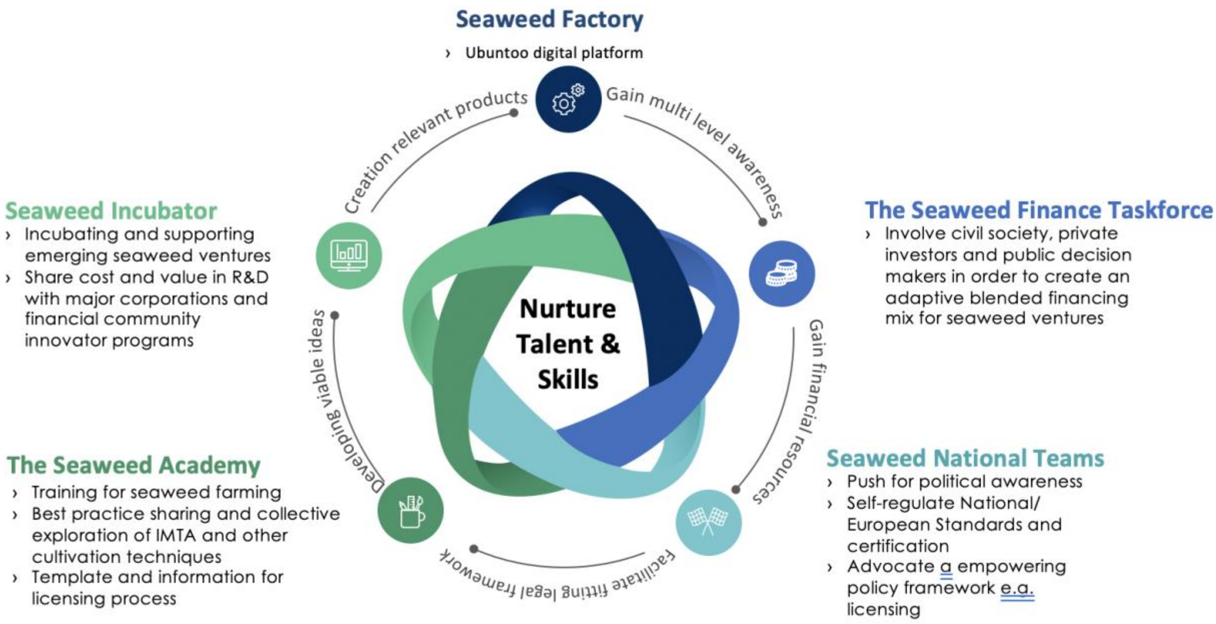
3. Digital Collaboration Platform

The need to nurture initiatives on every end of the value chain including bottom-up talent, skill and solution creation, which currently seems to be missing within the market (Valderrama et al., 2013; Seaweed for Europe, 2020). Seaweed solutions' future success requires new ventures and talents to emerge. Here, the recent digital platform for sustainability community, Ubuntoo, emerges. AI based platform which brings together investors, research and entrepreneurs in order to start a dialogue, knowledge and best practices sharing. This does not only aid entrepreneurs to enter the seaweed market but also raises seaweed to investor's radar. Investors can ask ad hoc questions and thus entrepreneurs can learn first-hand what is needed and investors may establish more trust in thus blue ocean market. Recently the Coalition Seaweed for Europe and major players like CocaCola have entered the platform in order to stay up to date and leverage innovations to their fullest potential. A co-creation of the ecosystem is needed which is proven to also increase the acceptance of strategies and business models among stakeholders which ultimately helps to speed the process and integration of products (Barbier et al., 2019).

Thus, an interactive platform for entrepreneurs and investors to further nurture ideas, talents and to ensure private investors' attention while growing demand and general awareness emerges as great strategy for collaboration. This helps to lift the identified key issue of the seaweed market, technical knowledge and skills gap for seaweed farming and product development (Valderrama et al., 2013; Seaweed for Europe, 2020).

The Seaweed for Europe Coalition has entered indeed the Ubuntoo platform just recently in order to connect stakeholders, which will act as basis for further strategic recommendations. Inviting scientific academia, entrepreneurs, farmers, investors and major corporation, an incubator mix like a **seaweed initiative factory** may be created. Following the shared cost and value approach the required research and development may be facilitated by investors and major corporation through infrastructure and network sharing.
A **Seaweed Academy** as toolkit for entrepreneurs may prove to be advantageous. This may include application **templates for licensing and best sharing practices** following the example of Green Wave, an American NGO which created a tool pool for regenerative ocean farming which trains and connects stakeholders (Seaweed for Europe, 2020). Furthermore, a **finance taskforce** with workshops on Ubuntoo may help entrepreneurs to understand and thus utilize a blended financing mix for its commercial products and ecosystem services. Here the business case of Ocean Rainforest company that raised $1.5 million investment through close collaboration with the civil society, WWF NGO and private investors (Seaweed for Europe, 2020). By including and mobilizing vast amount of talents as well as financial community and civil society seaweed, a digital platform may form enough market strength to push from national strategy change eventually. Here dedicated teams may start to involve political decision makers in order to raise their awareness, sustainable knowledge and thus adapt current lacking framework for standards and licensing. The following figure depicts these above-described opportunities for creating a digital platform for stakeholder dialogue and involvement to ultimately nurture talent, skills and product ideas, one of the fundamental work streams for scaling seaweed.

Figure 9: Multi-stakeholder Seaweed Factory



(Source: Own Elaboration)s

4. Sustainable Business Model – Case Study

The following analysis of a sustainable business model implication for successful seaweed scaling integrates the learnings from the discussion of findings. As established previously PHA plastic alternatives based on seaweed represents an innovation potential for European players as current market behavior of major corporations like Cocoa Cola and Pepsi & Co hint towards a growing demand for product solutions. Here ventures may aim to accelerate research and innovation to stay upbeat with the market and current global markets. This may enable European players to enter successfully the emerging market of biotechnology with high innovation and profit potential (Barbiert et al., 2016).

The startup NOTPLA, established in 2018, may act as guiding example for integrating strategies above. NOTPLA has developed a technique to extract PHA plastic alternative components from seaweed to produce, plastic alternative films and sachets. In contrast to the rising PLA plastic alternative, seaweed based PHA biodegrades within 6 weeks without any further industrial treatment (NOTPLA, 2020). Furthermore, its production and cultivation does not require land, water or fertilization for crop feedstock.

Its *key activities* and business model are grounded in the cost and value sharing and learning principles, previously discussed. By focusing on local production and fostering local infrastructure and supply, NOTPLA has created a leasing mechanism of its technology for other entrepreneurs eager to enter the market. While this offers NOTPLA an additional *revenue stream*, it reduces fixed costs and thus risks for other stakeholders and accelerates market structure and organization for NOTPLA products. Here cost and value are equally and transparently shared, the machine leasing design is expected launch by 2021.

Furthermore, byproducts of the processing PHA plastics are sold to other industry sectors, which reduces the costs for PHA products. Furthermore, in order to create awareness and a demand pull, NOTOPLA partnered up with event organizers that may serve drinks in the NOTPLA sachets as event gag. This will *generate awareness and foster relationship with potential customers*.

Furthermore, NOTPLA follows an interdisciplinary approach in *human resources* in order to fully understand complexity of seaweed products and leverage upon various strategies. The team includes chemists, engineers, designers, entrepreneurs and marketing specialists. This way NOTPLA can work simultaneously upon the previously mentioned work streams.

These *key activities and resources*, partnerships and machine leasing, from NOTPLA follows the sustainable business model, combining internal and external resources in order to create a high value proposition. This *value proposition* includes ease of market entry for other ventures, building of infrastructure, plastic alternatives for customer sustainability and thus ecological benefits.

Furthermore, NOTPLA has started to create an *innovation hub* in London for other ventures to join. This will increase the proximity between innovators and infrastructure leading to a higher exchange of expertise, ideas and reduction of transportation costs. In terms of financing and partnerships, NOTPLA entered the Innovator in Residence program from Sky Ocean Ventures that brings together investors and entrepreneurs. Therefore, NOTPLA may aim for cocreating a digital innovation hub connecting global seaweed leaders, decision makers and investors.

Recommendation & Implication for Future Research

Having defined the natural environment of seaweed as ever changing, the connected social and economic systems are therefore complex and uncertain, and research underexplored. Thus, this thesis utilizes general rules and researchers are aware that not the complete ecosystem dynamics will be captured and understood within this research's scope. This research aims to add value by combining managerial aspects with scientific insights, from interviewees to secondary literature. It acts as summarizing piece that gives reader a general overview of the marine and specifically seaweed ecosystem and the associated economic and social value and risks. Summarizing and collecting latest knowledge development in both ecology and business management research streams, this research may act handbook for future research.

Emerging themes and their elaborated analysis highlights strengths and weakness of current technologies, innovations and leadership styles. Here more research is needed to shift theoretical concepts into practical experimentation and thus add further insights. Within the cultivation process, future research may further analyze the use of flying vessels for monitoring ecological characteristics e.g. biomass change over time, water temperature, water dynamics and create a software that interpolates such multi source into easily interpretable recommendations. This will not only save time and costs but also strengthen Europeans agenda on technological development and artificial intelligence agenda. Future research here can also shed light upon wider ecosystem impacts from seaweed and thus create more certainty for political decision making, civil society and investors, which will great help seaweed scaling. Furthermore, IMTA techniques are still in their infancy and the impact of multiple species within one cultivation cycle are still unknown. Here field experiments are needed to understand and define the most optimal species mix for a general creation of higher value and growth efficiency.
Within the processing stage, modular production design, collaborative infrastructure building and bio refinery are all fields that are in high need of future research to overall increase biomass supply, reduce waste for achieving a circular economy and create valuable products for a demand pull.

Another very interesting research stream may emerge concerning impactful partnership and collaboration strategies and roadmaps. Here learning journey emerges as viable tool but remains mainly theoretical and needs further practical exploration. System leadership guiding principles of resilience, paradoxical and redundancy thinking are very promising however lack in a comprehensive and conclusive framework for internal corporate application. Here communication and leadership experts may further research tools to integrate such into corporate culture, structure and relationship building practices.

Furthermore, the reader must note that seaweed is very much dependent upon eternal environment, thus research into cultivation practices may have a limited validity for other water regions. As this research aims for qualitative insights, the researcher acknowledges that quantitative data and measurements are as equally important and needed for a holistic depiction of seaweed potential and risks. Thus, future research may deep dive into different recommended workstreams and generate more scientific based data. This will also aid the later stage creation of scientific and reliable key performance indicators of seaweed and thus the basis for future strategy formation.

The same applies to the interview sample. Although, it constitutes a diverse and interdisciplinary stakeholder range, these are European based informants and thus their insights might be limited in reliability and viability for other world regions. Researchers aim to mitigate this by sourcing international secondary literature in order to create general insights, however here future research may expand the scope more towards an international audience.

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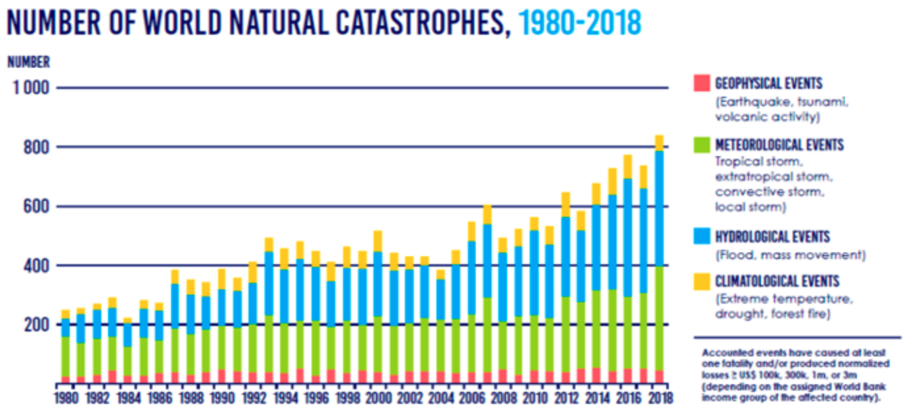
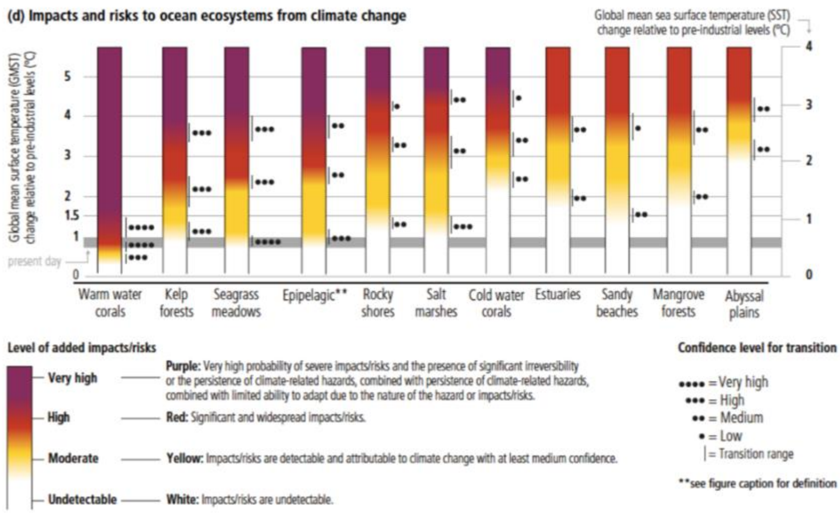
Appendix

Appendix

I. *Number of Natural Catastrophes* (Systemiq & Club of Rome, 2020)

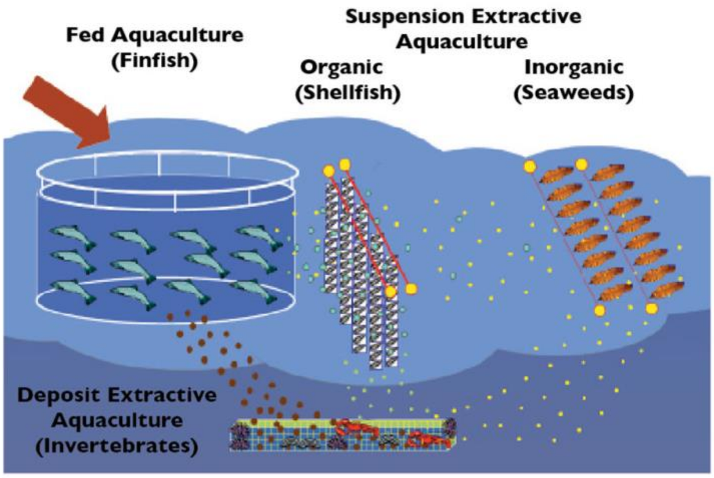


II. *Estimated changes and risks upon the marine ecosystem (IPCC, 2019)*

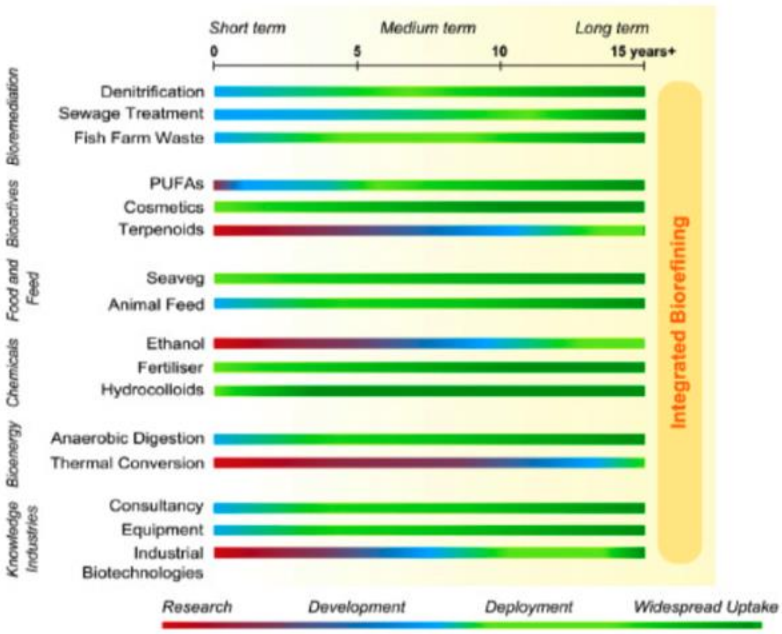


** The epipelagic refers to the uppermost part of the ocean with depth <200 m from the surface where there is enough sunlight to allow photosynthesis
(Source: IPCC Special Report “On the Ocean and Cryosphere in a Changing Climate” (Summary for Policy Makers), 2019)

III. *integrated multi-trophic aquaculture waste circulation* (Chopin et al., 2010)



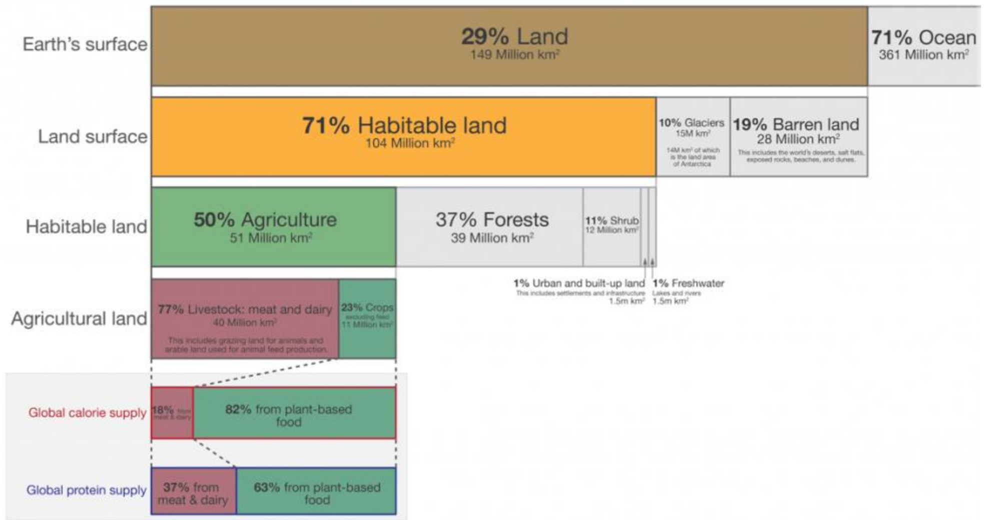
IV. *Timescale for commercialization of seaweed in the UK (Capuzzo & McKie, 2016)*



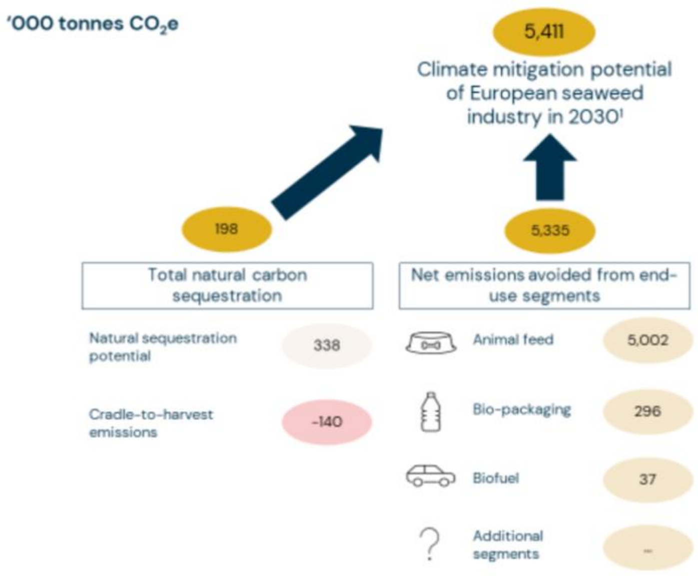
V. *Seaweed species suitable for European waters (Seaweed for Europe, 2020)*

Kelp and algae belong to the 72 500 subspecies of seaweed, for example, Saccharina latissimi (sugar kelp) is utilized for animal and human food and can adapt easily to European colder waters. Dabberlocks (Alaria esculenta) and dulse (Palmaria palmata) are used for food and cosmetic. Polysaccharides derived from seaweed can form hydrogels for additives and binders in different sectors e.g. thickeners, ice, beer (McHugh 2003).

VI. Land Occupation by Agricultural Activity

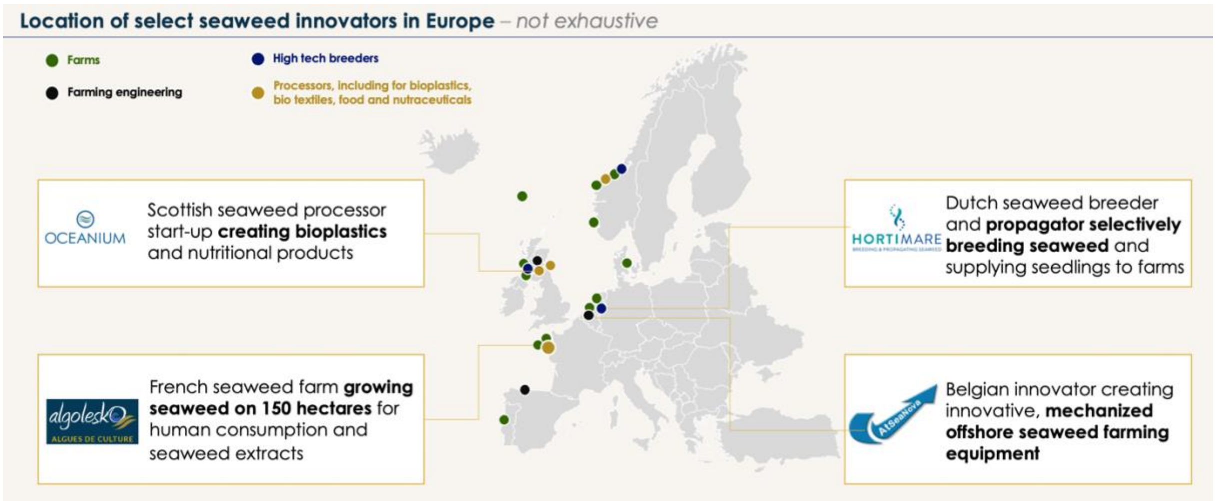


VII. *Climate Mitigation potential of seaweed for Europe* (Seaweed for Europe, 2020)

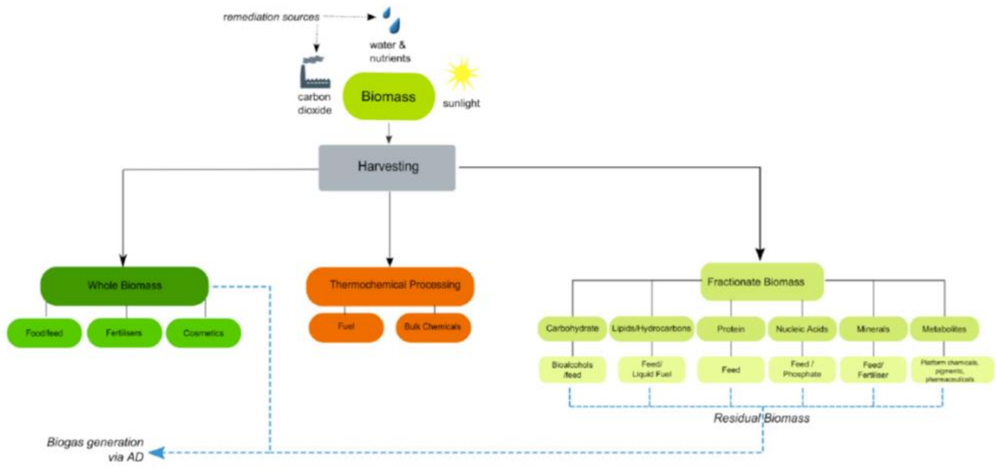


VIII. *Strategic priorities within the seaweed market* (Seaweed for Europe, 2020)

IX. *Seaweed innovators in* Europe (Seaweed for Europe, 2020).



X. *Biorefinery process & products for algal biomass* (Capuzzo & McKie, 2020)



XI.

RESEARCH STUDY - INTERVIEW PROTOCOL

STUDY OVERVIEW AND DESCRIPTION

This research *on System Leadership & Innovation for Corporate Sustainability along the seaweed value Chain* is promoted by Sarah Peschko under the scientific coordination of Professor Stefano Pogutz and Luigi Bocconi and CLSBE University.

The purpose of this study is to investigate emerging ecosystem-based management theories, strategies and business models for a successful resource management of seaweed. The study will provide valuable information to understand how companies deal with diminishing environmental resilience and how to regenerate it while creating economic and social wealth.

INTERVIEW STRUCTURE AND QUESTIONS

In order to collect valuable data and information for the study, we are carrying out a first exploratory research based on semi-structured qualitative interviews, involving leading companies and organisations within the European seaweed market. Furthermore, this study appreciates the knowledge creation potential by multi stakeholder perspectives, thus sustainable consulting experts, technological providers and terrestrial agriculture experts will be also interviewed. In particular, we are kindly asking you to participate in an **interview** that aims at investigating how your company/organisation is addressing the issues related to a lack of market infrastructure, organization, limited scientific knowledge and simultaneously pushing demand for seaweed products.

Your participation in this interview will take maximum 1 hour of your time. The following depicts an indicative list of questions and different focus within the interviews. These are however subject to adaptation or filtering according to your field of expertise and possible emerging themes.

Thank you in advance for your kind collaboration.

Part 1 – Personal Introduction & Perspective upon Seaweed's Aquaculture

This part acts as introduction to you, your field of expertise and your general perspective upon and possibly even your experience with ocean regenerative solutions like seaweed.

1. How did you enter the seaweed market?
2. What is your role within the market?
3. What is your perspective upon aquaculture of seaweed?
4. Do you see a market for seaweed's ecological benefits?
5. What is your experience with seaweed/aquaculture?
6. What market potential and opportunities do you see here?
7. What uses and thus species of seaweed do you focus upon?
8. Do you have insights upon current processing and cultivation procedure?
9. What are your experiences during a process of new product market entry, especially for cultivation practices?

Part 2 – Challenges & Needs

This part focuses upon challenges ands hindrances that you may have experienced yourself or learned about from associated initiatives.

10. If Seaweed bears so many opportunities, why have we not yet scaled it within Europe?
11. What is the one thing that you try to accomplish that is more ambitious than the resources of you and your partners have now?
12. What economic prerequisites does seaweed need to entail for a successful scaling?
13. Do you experience or perceive challenges towards scaling European's seaweed market?

14. Do you perceive any ecological risks or considerations?

Part 3 – Solution Innovation

This part dedicated itself to solutions that you may envision to the challenges that you have mentioned in the previous part. Here obviously the questions are dependent upon previous answers.

15. Where do you see direct investment need in order to enable fundamental conditions for seaweed scaling?
16. What innovations do see as the most impactful?
17. What is the competitive advantage that your company builds upon?
18. What is your perspective on current bio refinery progress and other technologies for biomass efficiency?
19. Can seaweed industry learn from other sectoral initiatives and if yes, which ones?
20. How can we ensure that wider ecological impacts of scaled seaweed farmed are considered and if negative, prevented?

Part 4 – Corporate Governance & Competencies

21. What skills and competencies does a company need to possess to ensure successful management of solutions like seaweed?
22. What were your main learnings within your projects/Collaboration/ organizational transformation?
23. What business models do you see in the aquaculture as viable options?
24. Do you see collaboration, cross sectoral, internal market as a feasible approach?
25. What is needed for a successful collaboration?

26. What new forms of cooperation do we need to establish, and how can governments support this?
27. How are companies transforming associated business risks into opportunities to reshape their strategies and to innovate?

28. Any other insights that you would like to share

XII. Interview Summaries

Company A

Position along the value chain: Climate Action Manager at Corporate Sustainability Initiative

You call yourself an ocean enthusiast, have dedicated your last year in building business models and infrastructure for the seaweed economy. What got you into it?
I am simply amazed by the nature and especially the ocean ecosystems. How everything plays its role in such a dynamic manner that we are only now starting to understand. There is such value in learning from these mechanisms, to reenforce and regenerate them. The climate change triggered natural impacts are not our enemies, we can perceive them as a sign of system imbalance and try to understand what it needs. These systems are the key for finding the most sustainable and long-term solutions. Before we have disregarded natural order, the indirect feedback loops and are now experiencing the harsh consequences.

Seaweed offers an opportunity for us to learn, experiment and transform. Everything is connected, seaweeds potential can only be unlocked when we adapt to its complexity. Integrating feedback loops more distanced impacts and stakeholders is called adaptive management.

What does this adaptive management entail?
Definitely an integration of various, diversified interest groups, understanding their perspective. Science will enable us to represent the nature and its needs in our planning. For example, through bio mimicking natural ecosystems we can detect that its resilience stems from diversity of sources, location, size. Therefore, opposite to possibly our first intuition, we should keep the redundancies and diversity in supply, farming size, cultivation technique. From small to big farms, on- or offshore, wild harvest, integrated systems etc. There is no silver bullet, the combination makes it diverse and thus more resilient. A fundamental understanding in adaptative management is that the strived objective is also changing and transforming, that there is no single equilibrium but many of optimal stages depending on the surroundings.

This also means not aiming for optimizing 2-3 species but to continue exploring other species. Diversity here must be included in growth scenarios. Therefore, we need to accept redundancies in bot cultivation systems and species themselves.
Adaptive management is also expecting shocks and varieties in harvest and be prepared for such. This can be achieved through modular planning of productions technologies. Pooling resources and sharing technologies will allow for shared value and full usage of manpower and available infrastructure. During downtimes other marine species or even terrestrial products can be processed. Seaweed should be taken as an adaptive addition to the economy instead of a decoupled and new industry itself.

This would entail a complete transformation of fundamentals in management?
Yes indeed, but current economic and social crises has shown us that current systems do no longer serve us but we serve them with catastrophic consequences. We are lacking robust
European economic model is highly dependent on imports, overoptimized and standardized and lacking the robustness to face unexpected shocks, which are expected to increase due to climate change. We

need to start accepting that there are paradoxical objectives, and that the combination may bear the solution.

Do you believe that this is realistic to practice in near future in mainstream management?
Yes definitely. We are going through a learning phase right, understand that we believed in ignorance to have understood already, that there is so much more too it. We start to understand that this approach will actually benefit us. Here the right system needs to be build that incentivize all stakeholders to participate to be open to collaborate. Experience in other industries, e.g. agriculture, shows that the fairer the distribution of value across the value chain, the larger the drive towards creation of additional value, benefiting the value chain as a whole. Consider why for example should someone be incentivized to work towards creating more value if this value only ends up benefiting someone else?

And this what we aim for in the Coalition as well as the WBCSD, finding solutions that integrates all stakeholders as this does not only enable better solutions but also a faster translation into practice. What the Coalition is working on to create a platform for stakeholders to meet, exchange information and help each other out. We want managers to realize that ecosystem management is a continuous learning. We need flexible models that can adapt, be dynamic, flexible, transparent and informed. When it comes to information we need higher and more sensitive sensing technology to be better prepared.

Company B

Interviewee Position along Value Chain*: *CCO of Ocean Funding Initiative & Ecological Researcher

What inspired you to enter the seaweed market?
Literally the environmental impact and the CO2 sequestering potential. There are 2 major Carbon sequestration that me and Josef Davis are working on. One being during growth which permanently sequesters the carbon into the sentiments, nearshore. When you convert wet to dry you have a rate of 12% of which 25% contain carbon. During growth 50% of biomass break down, 50% of carbon is sequestered permanently. The other being seaweed products containing a much higher carbon intensity which reduces other emissions like methane when eaten by cattle.

There are other environmental benefits like seen in China where current aquaculture removes 6% of nitrogen and 34% of phosphorus draining annually into coastal areas. China has just recently stated that it expects 100% removal of phosphorous by 2026. But this is in China, these seaweed farms are literally so big you can see them from space.

By taking in such amount of nitrogen and phosphours, seaweed also represents an opportunity as bio stimulant. Nevertheless, these are low margin products from which we in the Western economy cannot compete with. Also for food products, seaweed is a more complete protein than most terrestrial sources, but the question remains how to value such benefits in the sense of market projections.

What do you perceive as possible challenges?
To put it simple, the supply for biomass. Seaweed has a great potential, but we are simply not there yet in terms of supply capacity. For example, displacing 1% of animal feed in the US to seaweed, it would consume the entire current global production.

For example, seaweed in theory is very suitable for biofuel as 85% is made of water which makes it very eligible for anaerobic digestion for biogas and fermentation for ethanol. Sugar kelp for example has a very high carbohydrate intensity which makes it a good feedstock for ethanol. But this is not new, I remember a study back in 1987 and we are still not at the required biomass to compete with any of the conventional materials. The input needed is very high, even if the US Department of Energy just put down 50 million USD to compete with first generation feedstock like corn. Scholars that I am in touch with rather see biogas a more realistic option but it is still not efficient enough.

*What is your perspective on current bio refinery progress?*Lots of possibilities if approached right. Seaweed contains a lot of valuable components like fatty acids, oils, pigments of which all can be used for the production of other products, that we might have not yet even discovered. So a bio refinery which is simply a system that can extract more from seaweed than we currently use, can create higher value products while producing lower margin biogas or animal feed. This can help these products to compete.

A research group calls this cascading approach. So to start with higher valued products like pharmaceuticals and the remaining biomass can go through anaerobic digestion for biogas.

Where do you see investment need?
We need much more funding and research here to further understand the health impacts, benefits and possibly even limits to ocean seaweed carry capacity. We know it has beneficial effects for fish in terms of taste, color and for cows and pig's health and growth but this needs more in depth research. I was just recently contacted by Project Drawdown to include seaweed as regenerative solution in the new book.

Also, currently there are no market mechanisms in place to fully value seaweeds benefits. Like biodiversity impact by offering a nursing habitat for marine species, especially when seeing coral reefs diminishing drastically. There is a company, BIOMAR, that found that feeding finfish with seaweed decreases the mortality of these as it cleans the waters, and less waste is poisoning the fish. This is the whole idea of integrated multi trophic aquaculture, which entails instead of exploiting only on top of the food chain, bigger fishes, we actually nurture the conditions in a bottom-up approach. Really promising approach!

Any other insights that you want to share?
What I keep telling my clients, we have a chicken-or-egg situation here. We need the supply and availability of sustainable solutions but also need to nurture demand meanwhile. Seaweed is not integrated fully in Western culture, we need generate a demand that is sufficient enough for suppliers to stock up. However the demand only comes with a warranty of stead supply. You see the challenges?! It is definitely a co-evolution!

We also need to speed up research efforts, we need to catch up. We have created a cognitive debt, not understanding the impacts, direct and indirect, of our innovations. And we are under time pressure concerning the climate change.
… Here I see the legislative power to play a significant role. We need a framework, higher certainty for private investors, subsidies for farmers.
I am currently trying to push with colleagues of mine for pure pollution farming for seaweed. We need to create a market for such ecosystem services.

Company C

Position along the value Chain: Business Development Manager at ocean initiative

Do you have experience with seaweed?

Specifically, in a project not but seagrass has gained great attention in our organization as well as in the general market. There are emerging blue bonds, public private partnerships- There are initiatives for creation ocean based finds, ETFs and blue carbon credits. The Ocean Finance Handbook in 2020 was one of the first to get investors and thus a general market awareness.

My current role is to manage the commercial development of the ocean initiative, how to create a viable ocean economy.

What you say is needed in the seaweed market in terms of business development, model innovations?

Well, I believe that for sustainable development the conventional, business models and the innovation process does no longer hold. Here the innovation, the transformation goes far beyond the organization and individual. This is an ecosystem model change, the way we perceive our environment, the relationships within it and our actions impact. Instead of simply transforming the business model within the organization, we need to establish first a general understanding of the interdependence of different stakeholders – shortly: we first need to understand more which will enable us to take more transformative changed rather than incremental which is unfortunately the current prevailing model change.

My recommendation would be to understand its multiple use and therefore the definition the stakeholder and all the different markets and sectors relevant to seaweed. This is a start for not only the businesses to broaden their focus but also for investors to understand the multiple revenue potential of regenerative solutions like seaweed.

As you have deep experience in business development, especially in the ocean, what was one of your most striking experience or learning when it comes to corporate initiatives?

Simply, the organization and governance needs to be more coordinated. What happens often is that before understanding and real research organizations ump to changing their business model in order to satisfy recent customer trends. No wonder that they often turn out to be less impactful. The second observation that we are making is that without real stakeholder dialogue you have a massive and uncoordinated number of initiatives. And our premises is always the number of members engaged is finite. Currently there is a lot of initiatives and also a lot of technology emerging, there is a lot going on basically, these need to communicate better.

Also you need the major corporations need to be involved as they supply not only financial resources but have the infrastructure new business models can leverage upon.

What are the major corporations or rather stakeholders you see relevant for the seaweed market?

Definitely the fisheries and any corporation connected to them as they are drastically facing diminishing fish stocks and thus have their main product lines threatened. Seaweed here can help to nurture and increase the fish stock, can act as feed as well as possibly new product lines. Also, corporations like Coca Cola that have entered the alternative plastic market, these should be also included.

The two should be married but are not: agriculture & aquaculture and finance stakeholders. Once you start to diversify the product uses and thus get a higher value of the market potential. Here you need more research, from feed to stimulants, pharmaceuticals to really be recognized as viable alternatives.

What do you see here as opportunities and risks?

How much of a parallel of current seaweed cultivation in Asia has been drawn to European market. Possibly Asian huge seaweed farming would act as great business case. How can you avoid any challenges of current markets like workers welfare, social value? We need solutions and models here that does not cause further problems. Here are different working streams to be tackled simultaneously, which still our knowledge is lacking behind.

NGOs are hesitant, they are hesitant to jump to see aquaculture as the solution to feed us in the future. If Europe was to embark on this seaweed movement, what are the negative impacts? How does it impact sea life?

You need to bring together like minded people but the most happens when working with them, solving challenges together. If the Coalition wants to be significant and impactful you need to bring every single stakeholder and work with them. We organize advisory meetings, identify needs and help to develop dialogues. It is about getting the right people engaged. And finance communities is vital here, what are their concerns, what are their needs to enter a seaweed high level discussion. This needs to be considered, quantifiable data, new approaches to measure success like carbon credits etc.

So what would you define as successful communication tool here?

Well of course when having different stakeholders from top down, you have their mindsets and preconceived image to handle with. It is not easy. What we found very helpful to create a report with risks and opportunities, using a case study of a country. Ask them what challenges and risks they are facing?

NGO community is overly suspicious, and you need them on our side. You got to demonstrate the risks are smaller than the opportunities, here the Asian market comes in. If they can demonstrate that properly maintained farms do not represent any threat. Here what helps different stakeholders to trust the movement is to bring about a standardization process, entailing voluntary market self-organization like certificates with which you can control practices and thus ecological impact. This also would ensure that European products have a competitive advantage towards Asian very affordable but less quality products.

You need the European Commission be involved, have them change regulatory frameworks so the financial community also can create more trust here.

What business models do you see in the aquaculture as viable options?

You need to be practical, you got to understand the market. What does it look like, what is the revenue and growth potential.

Analyze the data, you understand the stakeholder and where and how much money is available. What are the future stakeholders? Never ever make a business plan until you understood everything. This is the most common mistake here. Therefore, if you would start now with a business model you need to take it in a broader scheme to identify the remaining question marks, knowledge gaps and missing market frameworks. You first need to understand everything before you can plan a business here.

Company D

Position along the value chain: Business Consultant & Coalition Lead and Co-founder

What got you into seaweed?
We were working on a system change compass for integrating the European Green Deal. We offered examples of paradigm shifts and changes in the way we see our economies and interactions. We were looking for a triple win: profit, people, environment. Europe recent political changes represents a perfect platform.

It came to us that we want to steer in the ocean management: Solutions that do not consume land, nor water nor need fertilization, that decouple growth from resource consumption. Ocean solutions combine all of these requirements while even benefitting us economically and socially.

The heart of our vision is to promote regenerative solutions in the ocean, especially when it comes to materials and lower trophic food. Seaweed here emerges as Champion. Its has vast use potential! From food, materials, feed, pharmaceuticals, bio packaging, cosmetic, fertilizer to biofuel, seaweed seems to be a chameleon for future challenges. And the beauty is that is regenerative: absorbs CO_2, nitrogen, protects coastlines, its just amazing! Through Mimicry of the nature, we can learn so much more.

You have written the latest seaweed report with your team as well as co-founded the coalition. How did this start?
I was lucky to be able to visit actual seaweed farm sites and talk to the different fisheries and other stakeholder. There was a good story to tell after our research, there were market inefficiencies, which needed cross collaboration, strong and unified voice to overcome

The fishers that are sinking in their rising debt because they simply do not catch enough fish anymore. In our drive to be the most efficient we have managed to decrease fishstock immensely, that even hurts us now economically and collectively. We launched the Coalition to together strengthen our voice.

What is your vision in the Coalition?
To accelerate the seaweed industry development. We aim for a shared value approach which includes all stakeholders from major corporations to the smallest fishery. Only then can we reach for a common vision and the synergies can be fully leveraged upon.

We also aimed for diversity, members are farmers, ventures, processors, technological providers/developers, investors, incubators, from academia & science. Together we established a **quantified vision of market penetration and defined what is needed. The first report acts as a summarizing piece of technological aspects as well as qualitative issues in order to build a better economy.** We now need more research into technology and the underlying managerial implications for viable business models. Here a focus on partnerships and emerging technology streams have proved to be great fundamentals for sustainability business models.

What does that kind of scaling entail?
To realize our most ambitious scenario, we would need to grow seaweed production in Europe from currently 3 000 tonnes, from mainly wild harvest to 8 million tonnes, mostly farmed seaweed…

And you propose interventions?
Exactly, quite general fields that need expansion. We have 6 aspects, work streams that need support. Top-down to bottom up. Only then are we capable of really creating a business case and propose adequate business models. First being, principles how to develop industry to avoid agricultural failures. Here shared vision is the most underlying fact that you need. Second are the relationship between users, ecological systems, producers. Third being the resilience thinking, accepting the dynamic nature of oceans and species and plan accordingly and regeneratively. The fourth being to build an economic system that includes all stakeholders, socially just. Fifth being science based decision making, further research. The final one is to push for other economic evaluators, so CO2 sequestering, nitrogen uptake, which needs a market.

There is a growing momentum. The Green Deal grants require sustainable and regenerative investments. We got another 6 months financing. Jeff Bezos invests 100 million in seaweed, Elon Musk calls for a price for regenerative solutions.

What was your experience to work with such number of stakeholders while having to act fast?
It is very energy demanding. You must act visionary, master highest communication skills. Besides the general willingness to expand the market, you have different prioritizations, interests on the table. Communication tools are the key to generate a common understanding of the importance of each stakeholder.

If Seaweed is so great, why haven't we started to grow and harvest it already years ago?
Even decades, this is not new information. But you have big barriers, regulations. 99% of EU seaweed is wild harvested. To farm seaweed you need a license. We are not used to such activity, they don't know about seaweed a lot, aquaculture…So they evaluate you on the wrong criteria like offshore wind, salmon farming which is much more harmful in terms of emission, nutrient leaking etc.. It is a nightmare!

Also there is a high regulations on product market launching: e.g. organic vs inorganic arsenic. Seaweed has roughly 60-73%, inorganic, which is not harmful but decision makers are not scientifically informed enough to differentiate.

How is seaweed doing in Europe in terms of global competition?
Another barrier are costs compared to Asian products, so we need to create products where you can justify higher prices, so higher quality. Which still needs to be fully researched.

European investors don't have it on the radar, they don't have sufficient data points and insights either. A lot of barriers but none of them cannot be addressed, so we are still optimistic. Asia currently produces 30 million tonnes, most of it is consumed as foord
So we also need to nurture demand that fits our market and history and preferences, its not just food, there are other products available.

What would you say were your learnings from the last 6 months?
To start from interests, needs, it's a people issue. Good mediators for creating the right vision. Clear driving plan, with everyone involved, shared value here is important, if not they are not motivated and it brings higher legitimacy and thus speed. Also instead of leapfrogging the development, we need to first understand the market, the ecological setting fully to create adequate business models.

Company D & E

Position along the value chain: Business Consultant & System modelling for Seaweed Coalition

You were part of the SYSTEMIQ team for writing the Seaweed for Europe Coalition report, what was the most striking insight for you?
It was very interesting to analyse a plant that has been until now overlooked while having such a great impact potential in our strive for to outbalance climate change. The current discrepancy between the fact that Europe is the biggest importer of Seaweed while local production is in its infancy made us realize that here is a great social and economic benefit.

What was your role, what did you focus on?

I was the number woman, I kneed very deep into the different product segments and the potential market size, value, costs and jobs needed. We always started at the final volume of demand and production capacity, turned that into wet seaweed tonnes and so on. The difficulty here is to see what are the realistic demands, Europe is not used to seaweed, do we add it in its natural form or rather additives for health, blend it into cosmetics? While these final product questions are out there, we still need to trigger demand first. Seaweed has little awareness among the public in Europe. We need to stimulate demand and supply simultaneously. This challenge face other sustainable solutions as well.

What do you see here as steps to take?
On the production side we need to build an infrastructure and reliable supply chain or rather connect current available and even underutilized resources. For example, storage is available but players are not connected, we need cross sectorial collaboration. The distance between technology providers, seaweed players themselves and other aquaculture need to be reduced. So we did by building the coalition. Now a dialogue exists, synergies can be matched and fully leveraged upon.

What comes here always is yes we need to market seaweed, make it a smart and attractive solution. But meanwhile we need to catch up in our knowledge of the potential uses of seaweed and best cultivation. Europe has indeed promising waters but seaweed biomass efficiency is very dependent on the water conditions, sunlight and other factors. We need to accelerate science, invest in research to understand one the benefits and two the risks.

Also raising awareness and increase knowledge among politicians would enable a better and more beneficial legal ecosystem. Currently there is a lack of supporting market mechnaisms, actually even beyond that it is harder for sustainable solution to succeed.

What is possible in terms of advocacy for scaling the market?
Quantifiable potential. We need numbers, we need to get our target, the ministers, the businesspeople, the investors. We need to speak the language of them, quantify it! And Seaweed tells a great story. Its numbers show the triple impact it has on people, planet, profit. Nevertheless, the numbers, even the ones that we have published are very dependent on the next year progress, prices, volume and other business

aspects still vary. We combined stakeholders to start the dialogue, share best practices and make these numbers and a seaweed business case more reliable.
The first step is taken now with the coalitions in Europe establishing, now it means to work on the different impact streams to ensure long term prosperity.

While summarizing and creating all these formulas for potential market value we also that these serve as great basis for creating a market for the social and environmental services of sustainable solutions like seaweed. Key performance indicators including CO2 mitigation, nitrogen and phosphorus uptake, coastal protection.

What are your main arguments here?
Jobs potentials, which is higher than current European aquaculture together. And the opportunity for currently struggling fishers to generate new revenue. Lift the burden of currently struggling coastal areas. Also taking the learning form Covid-19, our current supply chains are very globally dependent and more balanced approach makes us more resilient economically. The production capacity is scaled so is our resource supply diversity higher, we are may become independent. Also very interestingly the technologies that helps seaweed data generation, research, cultivation and processing is also applicable to other organic biomass feedstocks, so plants. The learnings and the infrastructure that we build may really act as a paradigm for the planned and very needed European sustainable transformation, a fundamental shift.

Now it is up to the stakeholders to cross fertilize eachother with ideas, resource, cost and benefit sharing to really get a viable scaling. This bears a lot of potential. To start with is science integration into managerial strategies. We need science based and informed decision making. On the forefront here is data generation in order to define the most appropriate locations, where ocean ecosystems benefit the most.

Are there any risks?
Sure from investment too ecological risks, we have everything as seaweed has remained in stagnating infancy stage. We need to understand its role in other bigger ecosystems. We know the risks of monoculture as well as algae bloom if these overtake, we need to scan smartly the effects, even indirect ones. But exactly that’s why it so perfectly fits the European agenda for a sustainable, prosperous and social just future. This holistic perspective that seaweed requires for full scaling acts as good reference for other solutions. Also, if we invest now into generic technologies, procedures and strategies we can create a shared value approach that multiplies the win.

What are these technologies?
Biomass being the key future resource for any material, fuel, food replacement, it is definitely bio refinery in terms of processing that needs further expansion, research to make the extraction of valuable resources more efficient. Like this we can create a closed system, valorize the whole resource, to its smallest parts.
And then there is the cultivation technology. Until now it is very labor extensive, time consuming and not perfectly matched with optimal growing conditions. Here we need scanning technologies to understand the requirements and to better plan, understand what seaweed needs to grow more efficiently the biomass.
This enables to avoid the mistakes of the past on land from having low wages and emotionally struggling European farmers to continuous top soil loss and pollution of water ways. We need the right incentives bottom up and top down, combined forces.

Company F

Position at seaweed value chain: Management and Innovation strategy consultant

You have consulted many companies in their strive to become more innovative and sustainable. What do you see here as the key product that you deliver for success? What do you see as a challenge?

Relationship building requires communication skills, strategies, interest and common understanding and vision. Stakeholders need to open up from, all need to be appreciated and included in solutions. This is indeed a difficulty. I accompanied a steel and energy company to trigger new innovative markets in solar energy, the creative sessions need to be scientifically and number based while qualitative and social factors need to be considered. How to rate them, how to integrate them in a holistic way, this is the challenge.

<u>What are the skills and characteristics of a company and market stakeholders should have for sustainable solutions to flourish?</u>

The acceptance of the lack of the knowledge gap and being open to learn. Until now the environment has been taken and perceived as limitless, now new interest like social well being and environmental resilience come into play. Strategies have emerged indeed in the field of corporate sustainability but still we don't seem to be cracking the fundamental causes. Something is missing. What has come to life in order to close these gaps are coalitions, multi stakeholder roundtables in order to share knowledge, insights and solutions. A multi stakeholder perspective and insights may give answers and valuable addition strategies and challenges. The synergy with technology for example is a key lever here for example.

Here some of my clients have experienced difficulty to bring together perspectives and find common ground and vision. Until now the environmental objectives were selected by their fit to the overall financial objectives. Now we are facing paradoxical goals. Efficient resource supply vs regenerating the environment. A key skill here is to accept these objectives all, let them be explored for possible synergies and develop eventually. This ensures a general and companywide awareness of the complexity of ecosystems and business responsibility. Also instead of only considering direct impacts and quantifiable in the balance sheets, a holistic approach should be taken that benefits the environment and therefore the business long term profitability. This follows the paradoxical theory which entails accepting short term possibly conflicting objectives in order to leave room for those to develop in terms of research and strategies.

With a learning mindset, companies can continuously adapt and transfer, innovate themselves. This is the basis for any sustainability business model that aims for long term success. Things to consider for such business model is not only internal but also competition, latest research, so information and the general supply of skilled human resources. A business having understood these aspects can really aim for sustainable business models that may succeed.

<u>What can you there?</u>

We apply the Learning Theory here. It is of utmost important that a mindset prevails which appreciates learning and intertest to improve oneself and expand horizon. Company specific we create a learning experience that brings together internal and external stakeholders together let them realize the value of each and everyone and that only together the best solutions and long-term value can be achieved. Key for example is through different media and content to create communication on vision, exchange of personal drivers to trigger an identification among the stakeholders. What really proved to be impactful is the on site visits. Spending time off the regular office and go through the supply chain and ecological impact sites, create a dialogue. Afterwards we initiate brainstorming sessions and experience sharing trainings.

This can be again and again be revitalized by innovation hubs, some call it the fertilization clusters where stakeholders meet on regular basis to also prepare a public voice for such anew and not developed market. Continuing to learn from the interdisciplinary perspectives as well as to solve together common challenges like infrastructure, storage and manpower. Pooling resources and high proximity between stakeholders enable a cost reduction and efficiency. This helps to mitigate the lack of legislation and efficient market structure.

Would have a training and general theme for seaweed in mind?

What I tell my clients always it is according to a percentage rule. 70 percent on the job and observing, 20 other dialogue forms and 10% formal learning. So it is always dependent on the industry and challenge on hand. There must be supportive structure for development and data insight. A Learning journey along the seaweed value points is definitely important and already done by several coalitions. More research needs to be included and accompanied by technology. There must be a mix of tools from coaching to online to networking to simulations. There are simulation learning assignments in which stakeholders build together a the system, map it in a visual and insightful way. Tensions and tradeoffs between different interests and objectives are the starting point. In them lies the required complexity and adaptivity of solutions for the complex natural assignments. With science included, progress can be measured in terms of environmental, social and economical key performance indicators.

Company G

Interviewee role along the value chain: Senior Sustainability Specialist

Having studied geography and now being in sustainability consulting, what would you say is the most important to consider when talking about seaweed?

Definitely, the wider impacts of seaweed. If we start to cultivate in huge farms, we need to understand the impacts in European waters and species.

What impact do you mean here? We are aware of the positive benefits, are there negatives?

That is exactly the question and we are still not even aware of all benefits seaweed delivers nor the wider ecosystem impact. Like for example when seaweed is grown in masses on the water surface it will ultimately put species underneath in the shade, reduce their exposure to lights, which is vital for many marine species being autotrophic. It is vital to map habitats currently in the areas to understand overlaps and possible consequences.

I understand! What I read is that seaweed also protects oysters and other shellfish from higher currents and water rising?
Well, that is another impact to consider. Of course on one side for farming this may bring about beneficial scenarios. Massive seaweed farms would change the water dynamics, stemming from the grounds it has a bottom up effect, changing currents and possibly creating isolated climate systems. It therefore, changes conditions but also the habitats in the sentiment and water.

What should we do here? What are the available options?
Well the success of cultivating seaweed also in the long-term to first increase economic growth, social well being while regenerating the environment, we need to better understand seaweed. We need to monitor overlaps, changes in the environment surrounding farms.
We cannot simply grow without boundaries, we need to check, generate data. The Norwegian government has realized this fact and has introduced a regulation that any farm beyond 10 hectares needs a monitoring system.

Problem here is that current monitoring are very cost intensive and not offering readily available information, it needs first long series of modelling and interpretations.

Do you have technologies in mind here?
Lets start with the requirements such technology needs to fulfill, we need management protocols but also an integrated warning system when conditions change beyond a previously defined threshold, so we have the chance to intervene early enough! There are several indications from that.

We need to estimate growth and productivity in order to plan the infrastructure and demand behind it. These are currently measured by weight, chlorophyll level etc. This is neither cost effective nor giving us the right information. We still do not know the right point when to harvest seaweed to gain the highest biomass turnover. Software and visual detection in the air are really on top of my mind.

Company H

***Interviewee Position along Value Chain*: Co-Founder of *Seaweed Processor & Cultivator*: Animal Feed Products**

What inspired you to enter the seaweed market?

What stroke me the most about seaweed is its capability to mitigate climate change. Approxiamtely 9% of the ocean's surface is needed to help us offset additional nitrogen imbalances in water nutrient load and sequester enough CO2. Especially in the Baltic Sea a cleaning of the waters is needed, its nutrient load is out of balance due to fertilizers and heavy metal pollution, which poisons the fish. Seaweed comes in here as natural bio filter. Taking in nutrients permantly it can help to clean waterways in cities etc while it is alos super rich in proteins.

For what do you utilize seaweed, what are the competitive advantage that you build upon?

The mere use of seaweed for carbon sequestering does not make sense in economic sense. Current markets do not have the appropriate remuneration structure for such ecosystem services. However, when taking out and used for products like animal feed, seaweed can conduct such ecological services while offering a revenue stream.

Meat production or any animal related services are very land and labor intense, especially when considering current feedstock like corn and soya that need water, fertilization and land. Furthermore, agricultural sector is the highest committing. Seaweed can help to lift these burdens of the terrestrial agriculture.

With 0.1% integration rate of seaweed in cattle's daily food intake, one can reduce 50%-80% methane emission. Also the reduced methane emission also reduces the energy needed by the cow, unlocking 15% additional energy for growth. Thus, the feed energy conversion rate increases, the time until cows reach adequate meat level is drastically shorten to 14 months. There is an Australian researcher that also found that with seaweed feed, cows become more fertile and are less disposed to bacteria, which drastically decreases the need for antibiotics.

We are also looking into seaweed as a feedstock for a near aquaculture, Salmon fishing. Farmers have reported a pinker color and better taste, when seaweed is used as feed. This also again replaces the land intensity of current fish feedstock, corn.

What Seaweed Species are you looking into and do you feel enough equipped to scale such?

We focus mainly on Asparagus, the red seaweed. It **is in its very infancy of industrialization** but its high carbon content and capability of reducing methane emission simply has to be scaled. That being our vision, what is so special about what we do is that we are the first in Europe to grow such species on land. We cannot easily cultivate it in waters as it is labeled by Europe as "invasive species". Which is just a mere representation of the **lack of understanding and the inefficiency of current political structures in place**…. Asparagus exists already for more than 200 years here in European waters. Anyways, we went on land, studied for years its productivity in tanks and have found very promising approaches.

Could you elaborate more on the land-based cultivation, what are here the benefits or even shortcomings?

Of course, the first idea is to **prefer offshore farms as they do not require any land.** However, species like **Asparagus are very sensible to water nutrient load as well as seasons, thus it cannot be grown the whole year**. Onshore you have the benefit or controlling the water with technology, always giving seaweed the most optimum conditions to grow. Especially, **when seeing ocean ecosystems changing, water temperature and acidity climb every year, such onshore tanks may be more feasible in future for aquaculture.**

But yes, we must admit this is not the most sustainable way to produce, neither is a large scale possible a rather medium but continuous through the year. **To compensate this, collaboration carries a major role in our company's identity.** We have partnered up and located ourselves close to an oil refinery, of which waste heat is used to warm tanks and CO_2 emissions are directly put into waters for an accelerated growth of the species as well as carbon sequestrating. It extends the CO_2 life cycle and thus slows down the temperature impact, the longer it stays in the cycle the more is heat is trapped.

…. Land on cultivation is more expensive to set up and operate. There is a California study on different prices which depicts our daily reality: operational costs are much higher on land in terms of energy etc.. However, current European political activity and interests tends towards collective actions and cross sectoral collaboration. Thus such example may serve as a good incentive for oil industry to integrate bio based carbon sequesteration into their balance sheet.
It is definitely worth forcing the polluting industries to integrate such interventions and prolong the carbon life cycle. Our vision: 1 Gigafactory of seaweed like the one from Tesla for each oil refinery.

What are the market prospects? What requirements do they entail for seaweed products?
There are two ways you can determine the market size of Seaweed; we choose the demand side by segments. We have a very growing market when it comes to cattle feed, 64 million cows are currently employed in Europe for milk production. Furthermore, there are other cow segments like bulls, beef cows and offspring that also require feed Indeed, there are different scenarios from a desired integration rate of 50% vs a realistic one of 10% by 2030. But seeing the aquaculture rise so immensely the last years combined with European rising political awareness, we aim for higher.

Quite frankly we absolutely need to compete on price and quality. Asia is long ahead of us especially when it comes to high commodity products like food and feed. You have prices like 100 USD per tonne, which is Europe far from reaching. It is a race.

We have a choice, either be cheaper or generate such a high quality and benefits that higher prices can be defended. Investors that we talk to, who are willing to pay a higher prices still require a 3:1 Return on Investment. Good news is that investors are getting more educated and also consider qualitative or indirect benefits e.g. health, fertility and higher growth productivity of cows. Currently, we are at 5 Euros per kilogram without processing the product in any special way, we take it, dry it and mix the required species. Realistically we need a 2 Euro/kg to unlock the cattle market more offensively, that would entail 20 cents per cow per day, which is defendable.

Do you perceive any challenges?
To start with: regulation. As I told you already there is a general misunderstanding or even lack of understanding of these new aquaculture solutions. We are measured against even higher requirements than conventional, nature destroying practices. Here collaboration is very vital, we have just recently joined the Coalition Seaweed for Europe to together push here for the right setting that enables ventures likes us instead of making it more difficult.

Then we need a more feasible technologies for filtering and valorizing our products. Asparagus is very high in iodine which needs to be filtered. Currently we simply dry it, which is already very cost intensive, and then give it to animals. We are not able to extract the right and valuable things, this is not biomass effective. Bio refineries are emerging however no solutions yet that efficiently and with high quality separates products and maintain the bioactive compound that breaks down methane due to high temperature sensitivity.

Also, I experience our potential customers, current farmed to be threatened by us. That's the opposite that we aim for. We aim to change Farmers image. Back in history, they were center point, nowadays they are seen as the bad guys! The last thing we want is farmers to feel threatened by us! It is not them, it is the methane and emission of current food focus: cattle! We aim for a better image here! Increase their openness to try new things.

Where do you see direct investment need in order to enable fundamental conditions for seaweed scaling?
Public awareness and the associated willingness to pay. Education of potential users, getting into the heads and patterns of people, seaweed needs to be seamlessly integrated.

Also the drying technology is very expensive, here other sectoral partnerships are on our mind e.g. berries & mushrooms cultivators that also need microwave like drying. Also here better spatial planning and infrastructure through business clusters in places with high sun intensity, like desserts for solar panels can help to reduce transport need and offer regneratiev energy sources for processing.

Definitely, more technology development for cultivation, current seaweed lines are not the most efficient way and causes problems e.g., Philippines use plastic ropes, which end up in the ocean. While increase the efficiency of cultivation efforts, such brings about however also a dilemma: The more efficient and streamlined technology and processes are the less job potential of this sector, at least during cultivation. Packaging, processing, distributing remains labor intensive. All has its up and down sides: Onshore gives you more control, is indeed more expensive but also gives higher insights into seaweed growth. For example, a large scale factory can feed 20-100 000 cows may offer 20 jobs when streamlined, offshore less automated processes at least double if not more.

Company I

Position along Value Chain*: Vice President of *Seaweed Processor, Animal Feed

What inspired you to enter the seaweed market?
To be honest the realization what impact current agriculture and thus our food production has. This is unbearable we quickly need to reduce the levels of ammonia, nitrogen oxides and methane gases that are currently steaming through the roof. Meat production is the heaviest polluting among all. Solutions that may reduce these elements in animal waste are changing the diets and thus changing the microbial conditions in the rumen of cattle. Seaweed very much fits these criteria.

By feeding it to cattle it breaks down the methane emission as well as increase the food energy conversion.

For what do you utilize seaweed?
Until now we remain at focusing on seaweed as animal feed additive. This due to the higher cost pressure on general feed biomasses (150 Euroos per metric ton), with which seaweed cannot compete as well as the possible toxication with high iodine levels, thus solely 70g for beed and 55g for dairy cows. Generally it extends lactation and mineral content of the milk.

Pigs are actually a better and even wider market than cattle, which we also focus upon. Here shorter life expectancy offers more opportunities to stimulate growth and revenue for farmers. Also seaweed is proven to increase the immune systems of pigs, which decreases the energy needed by the animals to fight bacteria etc which can be used instead for growth. Higher weight also increases intestine surface and thus the mineral uptake of pigs which increases the feed conversion. Here Russia and China are on the forefront of trying these opportunities of seaweed increasing poultry and pig immune system against the general challenges of diseases.

We are also experimenting benefits for dogs or general pet food. There is also less of a control by the government, less regulations for transparency etc and pet owners have a higher willingness to pay. (Pet food): plant based, organic

What are the competitive advantage that you build upon?
The Challenge remains that all these uses are commodities thus current solutions are very low in price and there are too many other available organic solutions. Therefore, we build on the high health quality of these additives for animal feed. It has long molecules up to 30 polysaccharides which is great as protein and mineral source. Current prices of such are 1-4 Euros per kilogram, blended and more notrious costs up to 140 Euro per kilogram from harvesting in the ocean. Our price goal is by 2030 to be around 32 cents/kg vs current corn prices of 15 cents. Furthermore, European products especially in these commodity segments cannot be more than 10% higher than Asian products as farmers would then go to them.

Europe has cold mineral rich waters with high current for continuous fresh water compared to Asia were minerals get depleted. Cold species are green, here the EU has 70% EU potential, and 20% for brown algae brown 20% and red 10%. Red needs tropical weather is more seasonal and has many legislation here in Europe.

So summing up obviously, Asia has history and cheap labor but EU may outbalance that my focusing on high quality and using innovation & automatization.

What investment is here needed?
Technology to further diversify our portfolio. Bio refinery comes in here quite handy even if it is still at the beginning. With a system that filters high value products while producing lower value products we can add more revenue streams and make thus seaweed products overall more accessible. For example the opportunity to produce bio fuel. There Norwegian farm and research institute that suggests that with 5 centralized business clusters of producers with each having a capacity to create 15 million tons of wet seaweed we could generate 3200 million liters bio ethanol. This is simply inspiring while experiencing other ecological benefits like steep nitrogen and phosphor water uptake and creating an environment for marine species.

Talking to the Seaweed Coalition and its leaders, if we bundle our forces, invest in such technologies and let innovative products emerge we could offset greenhouse gases of nearly 1 million Europeans by 2030

Company J

***Position along Value Chain*: Sustainability Business Research**

What inspired you to enter the seaweed market?
The future challenges of biomass!! Steering our productions and materials towards bio based solutions for a more sustainable future, biomass becomes the most critical factor. Already now scholars are reaching to find the most efficient biomass.
And by no surprise, seaweed emerges as a champion! By not occupying any land it exceeds the efficiency of terrestrial plants.

What do you exactly do?
I am writing my PHD about an economic model for seaweed. In terms of what is needed in different resources and what markets to strike in.

What are your findings currently?
I believe just like you experience a boundary between the ecological knowledge out there, which is so crucial for seaweed scaling and the management theories available. **So to start with we need platforms for stakeholders to meet, discuss and exchange information**.

How do you envision such collaboration?
The importance lies upon information availability and thus the understanding and perspective of the decision makers. Therefore, start by bringing them together, exchange insights and needs. Only then adequate solutions, research etc can be conducted. This entails also collective ideas and business models like the multi trophic idea, by including until now price squeezed stakeholders like farmers you might even increase their openness to collaborate and accept new technologies.

There is a program in the Netherlands, called ProSeaweed which partners up with business experts to build a comprehensive seaweed sector. It has researched and proposed several fields for investment need.
One being the biomass. Currently the fully life cycle of seaweed is not really studied, during process it has massive losses, wasted biomass due to the lack of efficient technology. Animal feed, using all of the

biomass is not the most effective in nutrient and protein supply while energy production from seaweed is not resource nor cost effective.

What do you see here as a challenge?
The unpredictability of cost and productivity. The last 20 years studies have published price estimation of cultivation but they all vary, which makes it nearly impossible to predict, plan or attract investors. We have estimated of $155 per tonne up to van den Burg in 2016 estimate of 1850 Euros per tonne from the Northsea.
Either way productions costs need to be reduced and a homogeneity in productivity and general costs must be found. This can only be done by further research!

What are the next steps here then?
Scientific based decision making. First research, I mean we don't know how to best grow seaweed, nor do we know how to best process it and are far from understanding long-term effects on the environment when seaweed is scaled… That is a lot of question marks. It is a simultaneous development with time pressure.

When we introduce monocultural practices to aquaculture for the sake of biomass efficiency, we might risk disease outbreaks, biodiversity loss etc. Here we need technology to observe natural seaweed beds, which will help us to mimic these in farms and trigger the best sustainably optimal state. I have heard about a project in California using satellites for time and geographical scanning. Flying vessels makes sense for big seaweed farms for low cost monitoring over time. This monitoring might enable to understand the variation in growth, seasonaility, costs etc.

This sounds interesting, I will have a look into these technologies for basic monitoring. Yeah, you should, current practices really cost and take too much time. Not really promising approaches when have this kind of growth rate in mind. We need to accelerate such research efforts in order to prevent industry to leapfrog and cause again permanent damage to ecosystems.

Yes indeed! Lets come back to the main future challenge that you defined as the strive for biomass, what technologies or development can we find here?
This innovation program pushes for a cascading bio refinery approach. Really interesting in terms of using all biomass effectively from seaweed and start with the higher value product to achieve an economic profitability. This will in turn attract private and public investment which will in turn facilitate a mapping and thus scaling of the market. Therefore, key here is to find the best business models for cultivating and processing in a most productive way.
For this you need technology, we need to better and quicker understand the dynamics in the water. Scanning technologies must be employed to define the most beneficial conditions for seaweed's nutrient and growth productivity. Current research practices and tools or rather the most commonly used are very time and labor intensive e.g. boats.

Do you have any final words or insights you like to share?
Well basically if you summarize what we have talked about is that we need collaboration on all levels: research, cultivation, processing, advocacy or rather political governance, corporate strategies and customer engagement. We need more data for more innovation for scaling.

Company K

Position along the value chain: Zoology research Scholar

What is your perspective upon aquaculture of seaweed? Do you see a market for seaweed's ecological benefits?
Aquaculture is growing definitely, especially Europe.
Yes indeed, we call this eco anchoring, closed systems or Integrated Multi Trophic aquaculture. The idea is to combine marine activities for cutting costs and better plan the marine space. What I have seen

are a combination of salmons, oysters and seaweed. Salmon have a lot of waste, which the oysters biofilter and the seaweed prevents sludge. Oysters for example are very profitable so combining them with seaweed my help to share costs. Also seaweed breaks waves and thus protects the oysters better. In terms of seasons there might be also a match.

What holds us back from scaling these ideas?
To be honest, the basic questions whether to focus upon the other products and take seaweed as side product or the other way around. Different species, need different water conditions, which one to prefer? Which market strategy to follow, where to focus upon?

I think it is difficult to have more than two species: operational side, different customers, dfferent regulation, different quality insurance. How do u prioritize? Ecologically condition also varied for optimized growth of all.

What would be your idea here?
Until now seaweed had very little impact ecologically, thus not so much focus upon it in ecological sense. Therefore, I would take a step-by-step approach. First phase being when seaweed is a side product while its conditions in different scenarios is researched. You have nothing to lose here, you simply have to integrate it into something that we are already doing. There is a Norwegian company that combines research and private market of other aquaculture. They check for fish stock intensity, feeding patterns and what they are fed, often chemically induced food clouds water and decreases productivity of fish and seaweed.

It is simply a chicken and egg dilemma, research needs money but investors need more data to decide and be attracted to the sector.

What research do we need here?
I mean the optimal would be a setup that allows causal effect like % of that added will change % in that. But not even icon Josef Davis has done it. It is hard to trap, it is liquid matter here and ocean experimental setups are rare and expensive. Also questionable of reliability due to the differences in water conditions. An idea would be using salmon farming tanks, but the most optimal would that not be. We need to understand the carrying capacity of the ocean for seaweed, the possibility of pathogens, temperature. In general there is a lack of information of the wider spread ecosystem impact, mixing with native species etc.

There is company that researches upon rope stringing different light conditions, letting seaweed rotate. There is also pulse light experiments, but all in the starting phase. But this is very energy intensive, not really what we aim for. We could take here wind farms or other energy producing mechanisms in the ocean and combine it with seaweed.

What is also really difficult is the discrepancy between managerial scholar and ecological ones. We in scientific research we do not mind or even appreciate if we get a result of “not possible", at least we know what we cannot do. From my own experience, managers and investors in the back however struggle with impatience, they need return on investment. This will be a challenge as it is a blue market, a lot of question marks, more than 80% of the ocean still needs to be discovered.

And there it does not even stop, during processing it also remains an uncertainty?
Puh yes indeed, it is not very my expert field but bio refinery emerges as the main focus to create efficiently biomass. Polysaccharides and gelatin are the highest profit margin products. Current approaches use land, water intensive feedstock. That just simply does not make sense… We need to leave land for the increasing population. Third generation feedstock comes here into play, like seaweed, that does not compete for resources with human consumption.

But in general, upscaling is difficult due to inefficiency of current biomass creation. What I have read is that you can used **infrared lights, hyperspectral cameras and other radars in order to check for the growth rate and biomass behavior.**

You possibly know that European Commission has set up a Marine Spatial Planning and plans to integrate a multiple use technological platform: You think this is feasible?! Following the theory of getting conversation going between stakeholders will solve the problems?
Interesting question! I believe the conversation between private, public and civil society will more realistic than competing firms sharing best practices. What I experienced as great support is a regulating body. Like for palm oil, here a governing body can encourage practice sharing, establishment of certification and creation of a common vision. People need to be on the same page, we need to pull the strings together but we are also just humans. We are used to work within our boundaries, for own self interest, no we need to realize that only collectively we can ensure long term profitability for all players.

What I observed is that such efforts often get ahead of themselves, first marketing and getting everyone involved before having the science for it. Communication regulation must come first, to have a framework .
What I do and find very important is the shared value approach: Palm oil research but you got to talk to the smallest farmer, understand their pain points, their interests in order to fully create and transform current systems.

Do you have any final remarks or insight?
What really got me thinking is that we only take in 2% of current food is from the ocean but we keep on messing with the ecosystems e.g. with bycatch. We current use 100 million tons from the ocean and 10 trillion from land. We need to close this gap, there is no way around but we need new regenerative solutions.
Europe is a political beacon for exactly that, so great to focus on Europe as it has also the possibility to generate high quality products which is needed to augment prices etc.

Company L

Role along the value chain: Sustainability Research Scholar
What is your perspective about seaweed?
What intrigues me is that seaweed simultaneously hints towards so many beneficial aspects and potential while it remains a black box.

What do you mean with black box?
Fundamental questions and aspects remain open like the geographical, environmental impact when introducing a non native species in such masses. Also the benefits for human and animal health are only now being discovered and researched. And what is probably not new for you from the business perspective, we are far from having the optimized cultivation processes e.g. harvest season, drying, storage etc.. Here collective strategies are needed, we have so much already available, why do we need to build a completely new and separated industry?! Why not simply integrate it? But then you have the black box of collaboration, bringing everyone affected on the table…

In terms of cultivation, I have talked to on and offshore farmers, what is your insight here?
There are a variety of techniques, from multiple step farming to a singly unitary one. From tanks to ponds to open sea with lines or rafts. You also require nursery… all of these have their pro and con, from higher controllability on land to lower costs on sea. Until now the most used commercially are the ones on the sea due to lower operational and other costs.

What do you see as a challenge?
Well, we know that it offers an alternative biomass source which does not compete for land, water or other resources. But its scale is not comparable to terrestrial crops; I think it is roughly something like below 30 million tones fresh weight of seaweed, in comparison to 16 billion tons from terrestrial sources…

The exposure to light also plays a significant role, which is still not defined which level is the best. Too low and too high are both dangerous for seaweed and other marine species. There are researchers that check for the effect of pulse light frequencies. And the basic fact that the growth rate and biomass conversion varies significantly depending on location, wave strength, light exposure and nutrient load makes current research only limited relevant. Most research is obviously conducted in countries that have a historic used of seaweed e.g. China, Chile, Japan. Within Europe the most researched countries are France & Spain whose waters are not comparable to the Northern sea.

What would say are here intervention points that can help us lift these challenges?
Puh, research research! From all sites, ecologically, managerial and in combination with the most recent and updated technology. We need to understand our waters, the carrying capacity of such in order to avoid mistakes that we have done on land. The ocean ecosystem is already vulnerable and disrupted and seaweed indeed appears to mitigate some of these influences but what if we suddenly times the current amount by 100 times. I do not believe that there will be massive changes or dangers but still we need to make sure. Research is also not so expensive as some people imagine, we just need to utilize the most efficient technology. Like for example instead of equipping a boat with scientists, why don't we use satellites, drones which brings the data to us?!

How would you structure here the approach?
We need to start growing seaweed in order to understand its impact. Thus, I would integrate seaweed into current aquaculture, experience with multi trophic closed systems while monitoring. Monitoring is vital here. Having introduced seaweed in different places it is then a scientific based step by step approach. Monitor, understand, learn, intervene, scale sustainably.

Company M

Position along value chain: Technology provider for environmental assessment, CEO

Besides your visual site monitoring and image videos, you have entered the agricultural sector along a research project of German forestry's bark beetle infestation. Drones and ecological ecosystem research, how does that come together?
Data is everything, literally the basis of all possible interventions to any challenge. Only through understanding the environment you can be impactful. It is the basis for sustainable future. We have acted very fast in our previous strategies, aimed for yield efficiency, growth potential with fundamental lack of knowledge. As Albert Schweizer put it: "We live in a dangerous time period. Human kind is controlling nature before learning to control ourselves"

… and to begin this learning we need to understand our impact in a systematic way. Technology comes in here as enabler! It comes in handy as it enables deeper insights.

I have started talking to a Norwegian research institute which aims to generate more data and thus insights for aquaculture. Seaweed farms or any bigger farming needs monitoring. Norway has introduced such monitoring requirements. We don't know yet what a scaling would mean for other aquaculture and nature conditions.

It is like with the forests in Germany. The bark beetle has infected the forests which entails great wood loss. Monoculture of non-native species has made the trees vulnerable towards diseases. Furthermore, global trade of wood and other products has introduced species and pathogens that do not exist here in Germany. Hyperspectral cameras locked to the drones can examine the condition of the plants. Drones is here the enabler to create these imageries in a fast and low maintance way. With a help of a software everything can be automated and data can be seamlessly be interpretated. Current approaches are time consuming and often information poor, requiring intensive time to model.

It is a technology that can be used for various uses, just like seaweed. System Management and research can be synthesized by a combination of features. Drones can also attach and carry things like nets for seaweed. There is lot to come!

What is your current strategy for aquaculture?
Scanning the environment, help to accelerate the data collection and interpretations. What I learned from several projects regarding plant growth, productivity: monoculture brings about a vulnerability to the systems and ends up in the opposite what we aimed for: instead of efficiency you have a gravel loss in resilience and sinking resource capacity.

Comparable to forestation, kelp rainforests need a diversified and holistic approach. Monoculture of terrestrial strategies have brought about challenges with biodiversity loss beyond farming regions, pathogens and other disease issues. I have forest owners struggling with million Euro losses yearly. Therefore, the data from drones can warn farmers from a system collapse and the required diversity in order to avoid negative environmental consequences. Also in terms of current and appropriate locations, laser scanning can be of aid.

What do you see as a challenge and opportunity?
There are actually a few. From the ecological point of few for growing seaweed or any other aquaculture, the environment is dynamic, biomass, growth productivity is very much dependent on different factors. Here it needs precise 3D modelling and estimation of volume, depth etc. Here equipped drones can help to deepen the imagery to 29 nanometers. The laser already partly covers the vegetation cycle and the software that we have created to interpretate data is already at 95% accuracy, this has not been achieved by any other monitoring technology.

We are working in a space where established mapping techniques have not yet been developed. This will provide data to support informed decision-making about how to assess environmental impacts and manage natural resources.

The acquisition of geodata in agriculture is an important field with many sensible scenarios: Precision farming, biomass diversity, distribution of the nutrient supply in the field. But also for forestry. And they don't produce any pollutants.

Also the market is expanding rapidly from construction to agricultural monitoring, drones are a generic solution. They can to a millimeter precision scan the environment and identify the need for renovation, efficiency improvement. The data collected, analysed and categorized can help to prevent major crop losses, waste and identify the highest yield point of time. Here is the opportunity for investors to not only scale seaweed but taking it as an example of other sectoral wide application.

Company M – Technology Provider

Position along value chain: PR and Marketing Consultant & Head of Communication of

*What got you into drones?*My guiding motto is innovation and information can impact the world. Observing how quickly and elegantly Joachim's UAV photogrammetry and laser scanning drone-based data acquisition works these days. Within a few minutes, the drones could take a millimeter specific image of 2 hectare. The research and innovation potential of hyperspectral imaging, interpolation with satellite data and thus a multi-source RS pool of information has steeply increased in the last years.

*What innovations do see as the most impactful?*The integration of the multisource data, a software that makes information readily available. This saves time and costs and increases the researcher's insight. A seamlessly data integration is the way to go besides laser and image improvement.

What does this market need?

As you can this technology and data processing apply everywhere, whether terrestrial in agriculture, construction, forestry to aquaculture, from monitoring, scanning to disease and phatogens identification, we need a collaboration. A pooled resource allocation into research and development of technology solutions here is key for the speed of any sustainable market growth. I will send you later some of the latest sensing technology papers for seaweed monitoring. Especially in California is the research and technology employment wider spread. We should aim for this in Europe. Collaborating with TUM University and Google enables us to integrate the latest technology with scientific knowledge, it is really inspiring to see how much it can help us to understand and be more impactful in our strategies.

Also it should be an imperative for a specific seaweed farm size to have monitoring systems as it has environmental impacts, both positive and some negative. we have seen in many projects lately the increased spread of plant diseases. This also brings massive economic losses. A monitoring system here would enable more precise warning system. There is a study from NIVA that proofed that drone imagery gives an additional thousand times quality and resolution, nearly a million more data insights. The most accurate data capturing can be achieved.

Do you have any insight into the seaweed industry?

I have definitely read very interesting papers and saw a trend to invest into aquaculture. Especially in America the innovation towards seaweed has grown. It just makes sense however there is much more to explore in terms of biomass creation. It has so many product possibilities. We have talked to Norwegian research institute and we are really amazed how much you can capture. We aim to create a multi-functional technology cross different sectors, I see a lot of parallels to forestry and resource management and analysis to seaweed.

Synergies are to be taken and worked with!

Participant hat to leave after 22 minutes due to an important client call….

Company N

Position along value chain: Agricultural biology researcher for organic based medical solutions

What are your experiences during a process of new product market entry, especially for cultivation practices?

It is astonishing how much paperwork you need to do. There is no easy way of taking documents that were approved by other countries. Technologies that are highest end stage research are new in Europe, thus the licensing and approval procedures is very enduring. People in charge are not aware of the benefits from non-native but not invasive species to new technologies and cameras. It is indeed a struggle.

*What do you think is the key driver for seaweed market and can it be utilized to resolve this issue?*The simple strive for survival on the quality of life right now. We need to find urgently new solutions, that don't only replace common materials but also help us restore nature's strength in providing an abundance of resources. I have watched farmed soil to degrade, we lose daily topsoil, costing us billions. We need to take these learning and start new approaches. We need to prevent monoculture; we need to be open to new dynamic work streams and factors due to the ocean's nature. Only then can we utilize and expand markets and impact of natural ecosystem solutions.

Also ocean based solution for one ecosystem services like CO_2 sequestration, blue carbon, as well as the diversity and possibilities for resources remaining to be discovered. There is a major potential. Aquaculture is booming. But we need to be careful.

What do you see as a key challenge?

The uncertainty in cultivation of seaweed and the risk of plant diseases are one of the most challenging issues known among scholars. Every year we loos up to 30-40% of yield due to pests and other diseases since industrial revolution, among the most basic, important, and noteworthy issues in agriculture management.

What are here possible interventions?

Any agricultural practice should be better monitored, researched and experimented with in regenerative and energy efficient ways. We are all interconnected in a system, we are affected and affect other organisms, oceans etc., we must here plan our strategies and sourcing of material in way that does not too much intervene with the natural cycles. We need to be continuously informed about the state of crop or seaweed, in order to understand the causes possible, improve productivity and prevent catastrophes.

We need to stay informed, we need to know how to start to grow, where to grow, how seaweed or any other aquaculture or energy sourcing can be easily adapted into the ocean ecosystems. Seaweed farms are big, I think it is in China where you can see the seaweed farms from space. That is huge, that means when put on ropes there will be less sun light for other species, also seaweed takes in nutrient which is great at regions with too high nutrient water load but in regions with depleted levels this may become dangerous. Also seaweed grown from the sentiment breaks waves, changes current directions and general water dynamics. This moves species in the ground and changes temperature level and supply of fresh nutrients. This is great for oysters, feeding of fish waste from colonies in the seaweed farm or close to, but possibly for other species not.

So, you say that research and knowledge come first?

Yes and no. It is knowledge and awareness on all sides and points along the supply chain. From the framers to bigger corporations to customers. It is a simultaneous act of pulling strings in order to establish a flourishing market. We must come together. What I have learned is when scientists raise their voice and talk to the media there is something worth noting and adapting into our daily practices and solutions. Bringing people on one table together will also be key, science could better reach to decision makers and we could relearn our relationship with nature and our consumption levels. It is a cycle with all stakeholders being interdependent. The natural resilience impacts us as much as the resilience of our economic nonphysical constructs and our physical wellbeing.

What technology or innovation do you see here?

Well I believe it is different innovations for across all the different things to do. From ecological side, monitoring systems and data with high information content, to research to better produce biomass to new products. We need better technological equipment, that is also easily accepted in current legal framework in order to leverage upon the higher yield efficiency. They need to learn about the new techniques which are more regenerative. Currently I feel like sustainable solution do not only face a lack of awareness, investment, market movement and research but also gets higher requirements of biological limits, that is just impossible. Here needs a social and technological solution to make the process more transparent and informed.