Sustainable seaweed value-chains

Economics, consumer attitudes and environmental impacts

Sander van den Burg, Hans Dagevos and Roel Helmes

December 2018

WAGENINGEN UNIVERSITY & RESEARCH

Interest in the cultivation and use of seaweeds for various markets in the Netherlands is booming. There now are various commercial seaweed producers in the Dutch waters and a multitude of companies selling seaweeds and seaweed-based products. The European Commission aims for a strong growth of aquaculture in the EU, including seaweed, recognising that this sector has high potential for sustainable jobs and growth.[1] Seaweed aquaculture is also discussed in the context of the Dutch North Sea 2030 strategy. This document brings together information on economic aspects, consumer attitudes and the environmental impacts of seaweed production and use. The Dutch government wants to know under which conditions seaweed aquaculture in the Netherlands can develop. This information can be used for an informed discussion on the prospects for sustainable seaweed value chains in the Netherlands.

The document first provides data on known current production volumes, current and new markets. Subsequently, information on the consumer acceptance of seaweed and on the environmental impacts of seaweed production and use is provided. Tempting as it was, we deliberately did not include a calculation comparing costs and revenues. It is impossible to quickly calculate a 'break-even price' or 'expected market volume' since this requires more careful consideration. The different types and qualities of seaweeds, the various markets targeted and the diversity of seaweed entrepreneurs should be taken into account to do justice to this complexity and to the energy and resources invested by the emergent Dutch seaweed-sector.

What is the current volume and value of global seaweed production?

According to the latest FAO data on global aquaculture production of seaweeds (FishstatJ, release 3.04.9), the world production of seaweed in 2016 from aquaculture equalled roughly 30m tonnes, with a value of US$ 11.6bn. As illustrated in Table 1, by far the majority (both in volume and value) is produced in Asia. Within Asia, China is the largest producer with a production volume of 14m tonnes, representing a value of US$ 8.6bn. Second is Indonesia with a production volume of 11m tonnes, representing a value of US$ 1.3m, in volume followed by the Philippines and the Republic of Korea.

Table 1 *Production volume and value of seaweed from aquaculture (based on FAO FishstatJ database)*

Continent	Volume (tonnes fresh weight (FW)	Value (US$ x 1,000)
Africa	139,313	6,274
Americas	15,634	33,703
Asia	29,964,105	11,630,027
Europe	1,554	3,158
Oceania	18,782	779
Total	30,139,388	11,673,941

The seaweed aquaculture sector grows every year in size and value. The volume of harvested wild seaweeds globally has remained almost unchanged in the last decades, with reported harvests of 1.06m tonnes fresh weight (FW) in 2006; 1.29m tonnes FW in 2014 and 1.09m tonnes FW in 2015.

[1] https://ec.europa.eu/fisheries/sites/fisheries/files/docs/body/2015-aquaculture-facts_en.pdf and https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en

As of now, 221 seaweed species are commercially interesting, 10 of which are intensively cultivated (FAO, 2018). These are the brown seaweeds *Saccharina japonica, Undaria pinnatifida* and *Sargassum fussiforme,* the red seaweeds *Porphyra spp, Eucheuma spp, Kappaphycus spp* and *Gracilaria spp* and the green seaweeds *Enteromorpha clathrate, Monostroma nitidum* and *Caulerpa spp*.

How much seaweed is produced in Europe?

Based on the FAO datasets (FishstatJ), it must be concluded that seaweed aquaculture in Europe is currently a small sector. The largest producer in north-Western Europe is France with a reported production volume of 500 tonnes in 2016. In contrast, the volume of wild-harvested seaweed is much bigger. France alone harvested 55,041 tonnes in 2016 and total European harvest equals 293,324 tonnes. Various initiatives to cultivate seaweed are on their way, not only driven by an academic interest but also by businesses who pilot the cultivation of seaweeds. A map with ongoing initiatives can be found in the European Atlas of the Seas.2 The screenshot presented in Figure 1 illustrates where commercial seaweed cultivation takes place as of December 2018.

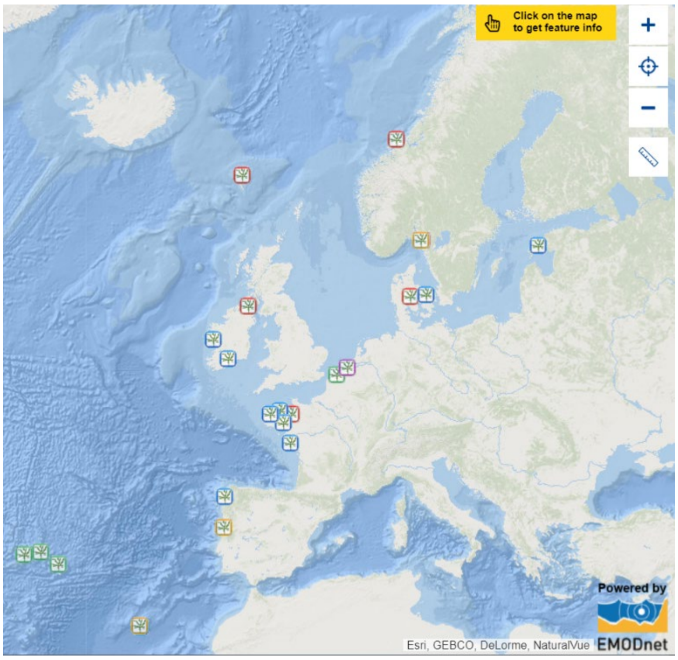

***Figure 1** Commercial seaweed cultivation in Europe (Screenshot of European Atlas of the Sea)*[3]

Various initiatives are not yet presented on this map. In Norway for example, the surface area allocated in 2016 to seaweed cultivation reached a total of about 277 ha along the coast, with 16 companies holding a cultivation permit (Stévant et al., 2017).

What are reported costs of seaweed production in Europe?

There a number of scientific publications in which the costs for seaweed production are estimated and/or calculated. From 1998 to 2011 a number of studies were published, with widely divergent expected costs for seaweed cultivation. Whereas some studies reported production costs as low as US$ 155 per tonne dry matter (DM), others estimated production costs to be US$ 16,630 per tonne DM. Van den Burg et al. (2016) report on the economic feasibility of seaweed production in the North Sea using economic modelling. They conclude that the production costs of seaweed in the North Sea would be approximately €1,850 per tonne DM (note that information in Table 1 relates to fresh weight). A closer look at the data reveals that a large share of total costs stems from the cost for seedlings.

Bak et al. (2018) evaluated a seaweed cultivation method that is applicable and economically profitable in the Atlantic Ocean. An offshore long-line seaweed cultivation system designed by Ocean Rainforest Sp/f was tested in the Faroe Islands and found suitable for cultivation in exposed and deep-water locations (water depth > 50 m). High costs of seeding material and costs of deployment were reduced by multiple partial harvesting. The total cost per kg DM of cultivated *Saccharina latissima* decreased when the number of possible harvests without re-seeding was increased (from € 3,673 to € 927 per ton DM). This work demonstrated that large-scale seaweed cultivation is possible using multiple partial harvesting in the Faroe Islands, and highlighted the need for further innovation to lower the cost of production.

What are the expected and reported benefits of multi-use?

The possibility of cultivation seaweed within offshore wind farms has been studied in various research projects. The MERMAID project focused on governance issues and stakeholder attitudes towards multi-use (van den Burg et al., 2016). Multi-use of sea is studied but no commercial multi-use projects with seaweed cultivation exist. At this stage of multi-use developments, the laws and policy obstacles seem to be the most visible ones. While there is a need to synergise laws, regulations, and policies across sectors, it is also necessary to coordinate across nations when transboundary MUPS are to be installed, as well as across governance levels (Stuiver et al., 2016).

[2] https://ec.europa.eu/maritimeaffairs/atlas_en.

[3] https://ec.europa.eu/maritimeaffairs/atlas/maritime_atlas/#lang=EN;p=w;bkgd=5;theme=638:0.75;c=-3390958.192188874,7217029.002522696;z=4

Röckmann et al. (2017) elaborated on the economic benefits of multi-use. One of the main hurdles that hinders use of offshore wind energy is the high cost for operation and maintenance (O&M) activities, typically representing a big part of the total costs (25-30%) of the total lifecycle costs for offshore wind farms). It is the logistical problems around O&M where most likely synergy benefits of multi-use platforms can be achieved. Logistic waiting times, for example, can result in substantial revenue losses, whereas timely spare-parts supply or sufficient repair capacity (technicians) to shorten the logistic delay times are beneficial. The study suggests that a cost reduction of 10% is feasible, if the offshore wind and offshore aquaculture sectors are combined in order to coordinate and share O&M together. This assumption of 10% reduction was also used in various studies investigating the economic prospects of mussel (van den Burg et al., 2017) or seaweed cultivation in offshore wind farms (van den Burg et al., 2016).

What are the most important markets for seaweed worldwide from an economic perspective?

Between 75% and 85% of worldwide seaweed production is used for direct human consumption in Asia. The second important application of seaweed is for production of thickeners (such as alginate and carrageenan), used in multiple food and non-food products. The volume, and values trades, of seaweed for these and other applications is summarised in Table 2.

Table 2 *Industrial applications of seaweeds (from Nayar and Bott, 2014)*

Seaweed product	Market value	Raw material		Final product	
	Million US$	Quantity (tonnes)	Value (US$/tonne)	Quantity (tonnes)	Value (US$/tonne)
Carrageenan	527	400,000	1,400	50,000	10,500
Alginate	318	460,000	950	26,500	12,000
Agar	173	125,000	1,200	9,600	18,000
Soil additives	30	550,000	18	510,000	20
Fertiliser (seaweed extract)	10	10,000	500	1,000	5,000
Seaweed meal	10	50,000	100	10,000	500

What are new market developments for seaweed?

Globally, many different new markets are considered interesting. The bioactive compounds in seaweed may be applied in a processed or isolated form in food additives (Pérez-López et al., 2014; Radulovich et al., 2015) and pharmaceuticals (Yang et al., 2015). Seaweed species may also contain other chemicals or chemical precursors and macrochemicals (starch, other polysaccharides, as well as proteins) to be used in chemical production (Bikker et al., 2016) or animal feed (Makkar et al., 2016; Peixoto et al., 2016; Seghetta et al., 2016). There are indications that specific species may even reduce enteric fermentation in ruminants (Kinley and Fredeen, 2015; Li et al., 2016), thus reducing climate change impact of production of beef or mutton. Seaweed-based products for these markets are subject of study or commercially available at small scale.

In the Netherlands, the emergent seaweed industry is driven by innovation in production and the growth of human consumption of seaweeds. There now is a wide range of products based, or containing seaweeds. Highly visible examples include seaweed burgers and seaweed pasta. Other examples include mayonnaise, seasoning mixes, cheese and even beers and liquor with seaweed. Apart from seaweed as a part of sushi, perhaps the most well-known seaweed product as such in this niche market is the so-called Dutch Weed Burger. This burger was introduced in 2012, and made its way to consumers via (fastfood) restaurants, canteens, food festivals, as well as the Dutch Weed Burger joint 'The house of seaweed' in Amsterdam since 2017. The seaweed used is grown by Dutch seaweed farm 'Zeewaar' in the Eastern Scheldt estuary. Worth mentioning in this respect is also the 2015 established company Olijck that has brought several seaweed-based products to the market, ranging from seaweed ravioli and tagliatelle to seaweed burgers. To mention another example, UmaMeats produces a burger and a sausage that are both hybrids because the beef used is mixed with 15% seaweed.

Is there research on consumer attitudes towards seaweed?

Currently, there is very little research into consumer attitudes vis-à-vis seaweed. To the best of our knowledge, the first empirical study with a special focus on consumer appetite for seaweed was published recently in a peer-reviewed journal (Birch et al., 2018b). Another rare example of a paper devoting attention to seaweed is a study by de Boer et al. (2013). In this case, seaweed is part of a broader analysis on new meat alternatives such as lentils, locusts, and hybrid meat. An exploratory study conducted by Onwezen et al. (2018) is also noteworthy and will be referred to in the remainder, but this research has not been published yet in a scholarly journal.

What drives consumers?

The abovementioned studies confirm that health is a key growth-driving factor from the consumer perspective. Many consumers perceive seaweed as healthy, nutritious, and natural, or, more specifically: safe, fresh, a good source of protein and of iodine, and low in calories (Birch et al., 2018a; 2018b). Particularly respondents who are more familiar with eating seaweed give higher scores to such perceived advantages. Such a self-reinforcing effect is not uncommon in behaviour: we fuel what we do by confirmative information about our doings ('action follows attitude') and we think better of how we use to behave ('attitude follows action'). The relevance for seaweed consumption is easily shown: information about healthy aspects of seaweed in terms of antioxidants, micronutrients or fibres will gain consumer attention in general and specifically of consumers who are receptive to seaweed products.

Seaweed is perceived as being tasty by a majority (59.9%) of the Australian respondents in the sample of the research by Birch and colleagues. Good taste is an undisputed precondition, but non-functional or non-hedonistic reasons are also relevant for consumer appetite to eat seaweed: more than half of the respondents noted that being sustainable (52.8%) and environmentally friendly (53.4%) were also relevant reasons for eating seaweed (Birch et al., 2018a). This finding shows relationship with the studies by De Boer et al. (2013) and Onwezen et al. (2018). In both cases environmental-friendliness is considered as an asset of seaweed by consumers. Overall, consumer studies to date do not give reason to treat seaweed products very differently than other food products: their (rise in) popularity among Dutch/Western consumers will depend to a large extent on their perception of seaweed products as tasty, healthy and sustainable. These are three key factors for consumer appetite and attention for foods which hold much broader validity.

What is holding back consumers?

One of the most important barrier to overcome is undoubtedly that seaweed is not part of the traditional Dutch diet. Despite the abovementioned beneficial features of seaweed, to Dutch consumers seaweed-based food products are unfamiliar foods. Birch et al. (2018a; 2018b) find multiple reasons for consumer reluctance to accepting seaweed as edible. Most critical barriers to seaweed consumption appear to be indeed unfamiliarity and lack of knowledge of the product category. Respondents do not know seaweed, feel ignorant about how to prepare and store it, what to serve it with or where to buy it. The study by Onwezen et al. (2018) also relates seaweed with such generally perceived drawbacks as bad smell, unavailability, not knowing how to prepare seaweed, and a potentially expensive product category.

These 'defensive' biases are deliberately or unwittingly mobilised to avoid behavioural change in order to stick to the food choices we are used to make. Holding on to our habitual dietary choices is a powerful determinant of food behaviour. Therefore, making the unfamiliar choice an easier choice is always a significant challenge. Status quo bias, loss aversion, fear of unpredictability, disgust ('yuck factor') and neophobia ('fear of the new') are hurdles to overcome to reach acceptance of new foods. And also with respect to rejecting seaweed, it turns out that particularly those respondents who are less accustomed to eating seaweed have higher scores on disliking seaweed, treat it as 'weird' or raise doubts or concerns about seaweed consumption as being good for one's health. De Boer et al. (2013) suggest that particularly those respondents who are attached more to a traditional high-meat diet are less keen to choose a seaweed product.

How can consumer demand be stimulated?

Introducing seaweed in combination with a well-known product such as a burger or ravioli is a market strategy that shows resemblance with the market introduction of plant-based meat substitutes. Taking seaweed as an ingredient of a hybrid end product such as a burger, wrap or pasta could be coined the 'seaweed by stealth' marketing strategy. This option is currently dominant given the situation that apart from seaweed as 'sea salad' or as seaweed salt, it is frequently added as flavouring ingredient (umami) and used in hybrid products.

Today's seaweed consumers will probably set the stage for future seaweed consumers. In contrast to laggards, early adopters of seaweed must be searched for primarily among the higher educated and higher income consumer groups as well as the more health-conscious consumers (Birch et al., 2018a; 2018b). Also younger consumers and 'responsible' consumers are expected to be primary and key target markets for seaweed products. Early adopters of seaweed products may be anticipated to be more adventurous and variety-seeking food consumers too. Onwezen and colleagues (2018) use the adjective 'innovative' to typify consumers who are more in favour of seaweed. De Boer et al. (2013) point to similar characteristics of trendsetting seaweed consumers in terms of high involvement, taste oriented, and high level of education.

With respect to seaweed products as 'trendy', Birch and colleagues emphasise that the potential seaweed market depends not only on end products but also on the way seaweed is produced. Next to product quality, also process quality matters. That is, production practices and the story behind the product (unprocessed, natural, ecological footprint, etc.) add to consumer appreciation and appeal. Put differently, seaweed consumption is not only about eating but also about experience. Symbolic value is not to be underestimated when it comes to building a future seaweed market. Especially not in times of growing urgency to incorporate new sources of protein in our diet that are more healthy and sustainable than animal-based proteins.

How does this relate to the 'Protein Transition'?

The 'protein transition' is about a dietary shift away from meat- and dairy-rich food consumption patterns towards eating more plant-based proteins and it could be helpful to accelerate consumer demand for seaweed products. The other way around, seaweed offers a possibility to contribute to this protein transition at large. Given the need to search for new protein sources to improve traditional Western diets as well as to feed the growing non-Western population in other parts of the world, it is to be hoped that seaweed will become part of 'the menu of tomorrow'. If seaweed consumption is associated with 'responsible consumption', the environmental and sustainable benefits of seaweed gain prominence. Eating seaweed, then, is particularly motivated by ethical concerns and awareness of the environmental impact of the food choices made. Consumers who are more mindful of such bigger issues such as protein transition and circularity could find 'good' reasons in this to justify a preference for eating seaweed.

Which environmental impacts play a role for seaweed cultivation?

Seaweed cultivation can take place close to the sea, using resources from the sea like seawater (on-shore) and in bays or in the open sea (off-shore). The most widely mentioned benefit is that seaweeds remove nutrients from the sea, especially near fish farms, and can limit eutrophication and possibly algal blooms (Aitken, Bulboa, Godoy-Faundez, Turrion-Gomez, & Antizar-Ladislao, 2014; Alvarado-Morales et al., 2013; Yang et al., 2015). Furthermore, seaweed cultivation attracts marine life, increases biodiversity, both flora and fauna (Radulovich et al., 2015; Yang et al., 2015). Seaweed captures heavy metals from its surrounding water environment.

Open seaweed farming systems for bioenergy seem very favourable with net carbon (in other words, carbon is sequestrated during growth) and energy balances (Aitken et al., 2014). High resource efficiencies are reported (Taelman et al., 2015). Still, there is considerable uncertainty regarding both the positive and negative environmental impacts of seaweed cultivation. There are indications that processing for conservation requires substantial resources, which could be required directly after harvest (van Oirschot et al., 2017). Intensive seaweed farming might encourage disease outbreaks or cause a decrease in the genetic diversity of local seaweed stocks (Cottier-Cook et al., 2016). Shading, turbidity and sedimentation are also potential environmental issues during seaweed cultivation (Langlois et al., 2014). Should it be necessary, the treatment of seaweed diseases can also have a negative environmental impact (Bernard et al., 2018).

It is hard to compare these environmental impacts since they are not systematically assessed across studies. From studies using Life Cycle Analysis (LCA) and derived methods, some priorities within the impacts considered in LCA can be derived. For on-shore cultivation, electricity use for pumping can dominate the environmental impact of cultivation and processing, causing climate change (Helmes et al., 2018). According to van Oirschot et al. (2017) climate change and fossil resource depletion due to conservation and to a some extent due to the hatchery dominate, as well as mineral resource depletion due to the seaweed farm construction. The importance of fossil resource depletion was confirmed in another case study by Taelman et al. (2015).

Which applications have been evaluated from an environmental perspective?

The processing of seaweed often produce multiple products or a main product and by-products. Fuel or ethanol production from seaweed is the focus of some studies (Kraan, 2013; Langlois et al., 2012; Seghetta et al., 2016). Several species of seaweed have historically been used as fertiliser and a soil conditions improver (Blunden, 1991; Chapman, 2012), and this potential application of the residues or by-products from the biorefinery of seaweed is mentioned in environmental assessments (Helmes et al., 2018; Pérez-López et al., 2014; Seghetta et al., 2016). The processing of seaweed for its applications shows a high variability and many processing routes are on an experimental or even hypothetical level, so that it's hard to derive trends in environmental impacts in the processing. Both energy and chemicals use required for processing are estimated to decrease upon scale-up (Taelman et al., 2015). Drying seaweed or its products will demand energy (Pérez-López et al., 2014; van Oirschot et al., 2017) also on an industrial scale, according to field observations. If process streams containing fractions of the seaweed need to be treated as waste water, this will result in high energy demands and greenhouse gas emissions from decomposing biomass. Both energy and chemical resources especially cause climate change and fossil resource depletion. Carbon dioxide emissions during ethanol production can also be major contribution (Seghetta et al., 2016).

How can the environmental impact of seaweed processing be reduced?

The environmental impact of processing seaweed can be reduced by following cascading principles: 1) apply the full mass of the seaweed in products and prevent waste, 2) take fractionation steps in the order that yield the most valuable compounds and maintain their functionality, 3) invest energy and chemical resources only if this increases the product value. Optimisation of the valuable compounds within the seaweed, and optimisation of the yield of each conversion step is recommended. This has been achieved for polysaccharides in Ulva spp. (Helmes et al., 2018) and is being piloted for other species and applications. Producing only energy from seaweed is not advisable according to these principles, while the complete use of the seaweed may require too much processing and may not be the most attractive option (Pérez-López et al., 2014). The waste from seaweed processing can be digested in order to produce biogas (Langlois et al., 2012). The high water content of seaweed could furthermore be reduced before transport, or transport could be eliminated by processing seaweed at the location of harvest. This would reduce the impact contribution of transport and of cold storage.

Which knowledge gaps remain regarding the environmental impact of seaweed?

The suitability of a seaweed application is not always completely evaluated, i.e. full carbon and nutrient cycles are not often modelled. Only a comparison with a benchmark can evaluate whether the resulting net emissions or absorptions actually contribute to an environmental impact. These comparisons are often implicit by assuming specific substitution scenarios (e.g. Seghetta et al. (2017). Such comparisons can be difficult to do in any case, and are a source of methodological issues (Brockmann et al., 2015). Critically evaluating the benefits from seaweed cultivation and application requires the development of novel impact characterisation methods as well, since many of the past environmental assessments have not addressed sea-specific impacts (Pelletier et al., 2007). Directly applicable quantitative methods are under development (Cosme & Hauschild, 2017; Taelman et al., 2014). Such methods should be further developed and tested in relation to seaweed aquaculture and use.

Closing remarks

The Dutch and European seaweed market is in rapid development, in part driven by EU and national policy initiatives to stimulate aquaculture (e.g. the Farmed in the EU campaign). This document provides information on the economic aspects, consumer attitudes and environmental impacts of seaweed production and use. This information can be used for an informed discussion on the prospects of seaweed aquaculture and in the Netherlands.

Further growth of the sector is expected (Groenendijk et al., 2016) but not all preconditions for development of seaweed value-chains in the Netherlands are met. From the perspective of this document, the following knowledge gaps are identified:

- What are viable business models for cultivation of seaweed, including the potential to combine seaweed aquaculture with offshore wind farms and taking into account the ecosystem services provided?
- How can seaweed product innovation be stimulated to develop attractive products for consumers, for example by removing legal barriers and/or development of standards and certification?
- How can seaweed aquaculture and use contribute to the development of circular and climate smart food production systems in the Netherlands?
- What are economic and social benefits of large-scale seaweed aquaculture and what is its use to society as a whole, given all other developments on the North Sea?

References

Aitken, D., Bulboa, C., Godoy-Faundez, A., Turrion-Gomez, J. L., & Antizar-Ladislao, B. (2014). Life cycle assessment of macroalgae cultivation and processing for biofuel production. Journal of Cleaner Production, 75, 45-56.

Alvarado-Morales, M., Boldrin, A., Karakashev, D. B., Holdt, S. L., Angelidaki, I., & Astrup, T. (2013). Life cycle assessment of biofuel production from brown seaweed in Nordic conditions. Bioresource technology, 129, 92-99.

Bak, U. G. (2018). 'Production Method and Cost of Commercial-Scale Offshore Cultivation of Kelp in the Faroe Islands Using Multiple Partial Harvesting.' Algal Research 33 (May). Elsevier: 36–47. https://doi.org/10.1016/j.algal.2018.05.001

Bernard, M. (2018). Seaweed pests and diseases. Proseaweed Dossier (project AF-16202). Yerseke, Wageningen Marine Research

Bikker, P., Krimpen, M. M., Wikselaar, P., Houweling-Tan, B., Scaccia, N., Hal, J. W., . . . López-Contreras, A. M. (2016). Biorefinery of the green seaweed Ulva lactuca to produce animal feed, chemicals and biofuels. Journal of Applied Phycology, 1-15.

Birch, D., Skallerud, K. & Paul, N.A. (2018a) Drivers and barriers of seaweed consumption in Australia. Conference Proceedings of the International Food Marketing Research Symposium, 13-16 June, PDF.

Birch, D., Skallerud, K. & Paul, N.A. (2018b) Who are the future seaweed consumers in a Western society?: Insights from Australia. British Food Journal, https://doi.org/10.1108/BFJ-03-2018-0189

Blunden, G. (1991). Agricultural uses of seaweeds and seaweed extracts. In G. Blunden & M. D. Guiry (Eds.), Seaweed resources in Europe: uses and potential. (pp. 63-81). Chichester: J. Wiley.

Brockmann, D., Pradinaud, C., Champenois, J., Benoit, M., & Hélias, A. (2015). Environmental assessment of bioethanol from onshore grown green seaweed. Biofuels, Bioproducts and Biorefining, 9(6), 696-708.

Chapman, V. (2012). Seaweeds and their uses: Springer Science & Business Media.

Cosme, N., & Hauschild, M. Z. (2017). Characterization of waterborne nitrogen emissions for marine eutrophication modelling in life cycle impact assessment at the damage level and global scale. The international journal of life cycle assessment, 22(10), 1558-1570.

Cottier-Cook, E., Nagabhatla, N., Badis, Y., Campbell, M., Chopin, T., Dai, W., . . . Kim, G. (2016). Safeguarding the future of the global seaweed aquaculture industry. United Nations University and Scottish Association for Marine Science Policy Brief.

De Boer, J., Schösler, H. & Boersema, J.J. (2013) Motivational differences in food orientation and the choice of snacks made from lentils, locusts, seaweed or ''hybrid'' meat. Food Quality and Preference, 28, 32-35.

Groenendijk, F. (Ed)(2016). North-Sea-Weed-Chain. Sustainable seaweed from the North Sea; an exploration of the value chain. Petten: ECN. Report no. ECN-E—16-024. https://www.ecn.nl/publications/PdfFetch.aspx?nr=ECN-E--16-026

Helmes, R., López-Contreras, A., Benoit, M., Abreu, H., Maguire, J., Moejes, F., & Burg, S. (2018). Environmental Impacts of Experimental Production of Lactic Acid for Bioplastics from Ulva spp. Sustainability, 10(7), 2462.

Kinley, R., & Fredeen, A. (2015). In vitro evaluation of feeding North Atlantic stormtoss seaweeds on ruminal digestion. Journal of Applied Phycology, 27(6), 2387-2393.

Kraan, S. (2013). Mass-cultivation of carbohydrate rich macroalgae, a possible solution for sustainable biofuel production. Mitigation and Adaptation Strategies for Global Change, 18(1), 27-46.

Langlois, J., Fréon, P., Steyer, J.-P., Delgenès, J.-P., & Hélias, A. (2014). Sea-use impact category in life cycle assessment: state of the art and perspectives. The international journal of life cycle assessment, 19(5), 994-1006.

Langlois, J., Sassi, J. F., Jard, G., Steyer, J. P., Delgenes, J. P., & Hélias, A. (2012). Life cycle assessment of biomethane from offshore-cultivated seaweed. Biofuels, Bioproducts and Biorefining, 6(4), 387-404.

Li, X., Norman, H. C., Kinley, R. D., Laurence, M., Wilmot, M., Bender, H., . . . Tomkins, N. (2016). Asparagopsis taxiformis decreases enteric methane production from sheep. Animal Production Science.

Makkar, H. P., Tran, G., Heuzé, V., Giger-Reverdin, S., Lessire, M., Lebas, F., & Ankers, P. (2016). Seaweeds for livestock diets: a review. Animal feed science and technology, 212, 1-17.

Nayar, Sasi, and Kriston Bott (2014). 'Current Status of Global Cultivated Seaweed Production and Markets.' World Aquaculture 45 (June 2014): 32–37.

Onwezen, M., Taufik, D., Bouwman, E. & Dijksterhuis, G. (2018) Consumentenonderzoek naar volledige en hybride zeewierproducten. Wageningen: WEcR & WFBR Consumentenonderzoek, Power point presentation. http://library.wur.nl/WebQuery/wurpubs/fulltext/448420

Peixoto, M. J., Svendsen, J. C., Malte, H., Pereira, L. F., Carvalho, P., Pereira, R., . . . Ozório, R. O. (2016). Diets supplemented with seaweed affect metabolic rate, innate immune, and antioxidant responses, but not individual growth rate in European seabass (Dicentrarchus labrax). Journal of Applied Phycology, 28(3), 2061-2071.

Pelletier, N. L., Ayer, N. W., Tyedmers, P. H., Kruse, S. A., Flysjo, A., Robillard, G., . . . Sonesson, U. (2007). Impact categories for life cycle assessment research of seafood production systems: review and prospectus. The international journal of life cycle assessment, 12(6), 414-421.

Pérez-López, P., Balboa, E. M., González-García, S., Domínguez, H., Feijoo, G., & Moreira, M. T. (2014). Comparative environmental assessment of valorization strategies of the invasive macroalgae Sargassum muticum. Bioresource technology, 161, 137-148.

Radulovich, R., Umanzor, S., Cabrera, R., & Mata, R. (2015). Tropical seaweeds for human food, their cultivation and its effect on biodiversity enrichment. Aquaculture, 436, 40-46.

Rockmann, C.; Lagerveld, S.; Stavenuiter, J. (2017) Operation and maintenance costs of offshore wind farms and potential multi-use platforms in the Dutch North Sea. In: Aquaculture perspective of multi-use sites in the open ocean / , Buck, Bela, Langan, Richard. - : Springer - ISBN 9783319511573 - p. 97 - 113. http://edepot.wur.nl/413244

Seghetta, M., Hou, X., Bastianoni, S., Bjerre, A.-B., & Thomsen, M. (2016). Life cycle assessment of macroalgal biorefinery for the production of ethanol, proteins and fertilizers–a step towards a regenerative bioeconomy. Journal of Cleaner Production, 137, 1158-1169.

Seghetta, M., Romeo, D., D'este, M., Alvarado-Morales, M., Angelidaki, I., Bastianoni, S., & Thomsen, M. (2017). Seaweed as innovative feedstock for energy and feed–Evaluating the impacts through a Life Cycle Assessment. Journal of Cleaner Production, 150, 1-15.

Stévant, Pierrick, Céline Rebours, and Annelise Chapman (2017). 'Seaweed Aquaculture in Norway: Recent Industrial Developments and Future Perspectives.' Aquaculture International 25 (4). Aquaculture International: 1373–90. https://doi.org/10.1007/s10499-017-0120-7.

Stuiver, M., K. Soma, P. Koundouri, S. van den Burg, A. Gerritsen, T. Harkamp, N. Dalsgaard, et al (2016). 'The Governance of Multi-Use Platforms at Sea for Energy Production and Aquaculture:

Challenges for Policy Makers in European Seas.' Sustainability (Switzerland) 8 (4). https://doi.org/10.3390/su8040333.

Taelman, S. E., Champenois, J., Edwards, M. D., De Meester, S., & Dewulf, J. (2015). Comparative environmental life cycle assessment of two seaweed cultivation systems in North West Europe with a focus on quantifying sea surface occupation. Algal Research, 11, 173-183.

Taelman, S. E., De Meester, S., Schaubroeck, T., Sakshaug, E., Alvarenga, R. A., & Dewulf, J. (2014). Accounting for the occupation of the marine environment as a natural resource in life cycle assessment: an exergy based approach. Resources, Conservation and Recycling, 91, 1-10.

Taelman, S. E., De Meester, S., Van Dijk, W., da Silva, V., & Dewulf, J. (2015). Environmental sustainability analysis of a protein-rich livestock feed ingredient in The Netherlands: Microalgae production versus soybean import. Resources, Conservation and Recycling, 101, 61-72.

van den Burg, S., M. Stuiver, J. Norrman, R. Garção, T. Söderqvist, C. Röckmann, J.-J. Schouten, et al (2016). 'Participatory Design of Multi-Use Platforms at Sea.' Sustainability (Switzerland) 8 (2). https://doi.org/10.3390/su8020127.

van den Burg, S.W.K., A.P. van Duijn, H. Bartelings, M.M. van Krimpen, and M. Poelman (2016). 'The Economic Feasibility of Seaweed Production in the North Sea.' Aquaculture Economics and Management 20 (3). https://doi.org/10.1080/13657305.2016.1177859.

van den Burg, S.W.K., P. Kamermans, M. Blanch, D. Pletsas, M. Poelman, K. Soma, and G. Dalton (2017). 'Business Case for Mussel Aquaculture in Offshore Wind Farms in the North Sea.' Marine Policy 85. https://doi.org/10.1016/j.marpol.2017.08.007.

van Oirschot, R., Thomas, J.-B. E., Gröndahl, F., Fortuin, K. P., Brandenburg, W., & Potting, J. (2017). Explorative environmental life cycle assessment for system design of seaweed cultivation and drying. Algal Research, 27, 43-54.

Yang, Y., Chai, Z., Wang, Q., Chen, W., He, Z., & Jiang, S. (2015). Cultivation of seaweed Gracilaria in Chinese coastal waters and its contribution to environmental improvements. Algal Research, 9, 236-244.

Contact

Wageningen Economic Research
P.O. Box 29703
2502 LS Den Haag
www.wur.eu/economic-research

Dr.ir. S. van den Burg
Researcher
+31 (0)70 3358 129
s.vandenburg@wur.nl

MIP Proseaweed
www.proseaweed.eu
PROSEAWEED For Food & Feed

Commissioners:
Ministry of Agriculture, Nature and Food Security, Topsector Agri & Food