Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 128 (2017) 491–496

Energy Procedia

www.elsevier.com/locate/procedia

International Scientific Conference "Environmental and Climate Technologies", CONECT 2017, 10–12 May 2017, Riga, Latvia

SWOT analysis for a further LCCA-based techno-economic feasibility of a biogas system using seaweeds feedstock

Jekaterina Krastina*, Francesco Romagnoli, Karina Balina

Institute of Energy Systems and Environment, Riga Technical University, Azenes iela 12/1, Riga, LV–1048, Latvia

Abstract

The main objective of the concept of sustainability is to meet various demands of burgeoning development and fast growing population in the best possible way while considering economic, social and environment aspects. Sustainable sources such as macroalgae or most commonly seaweeds, should be a subject of further investigations. Production of seaweeds is holding the capacity of different conversion roots and applications, such as human food and animal feed, biochemicals, bio-actives, bioremediation, bioenergy and biofuels, due to availability of various trace elements, minerals, vitamins and other biochemical elements, such as proteins, polysaccharides and less lipids with different application opportunities [1]. Seaweeds are widespread around the globe, however, its production is mainly located in Asian region and just a small share is represented by European countries. Not all the countries which have direct access to the sea practice seaweed cultivation or harvesting, including Latvia. Nevertheless, the results of SWOT analysis show that there are considerable amounts of strengths and opportunities for seaweeds to be potential as a feedstock for biorefinery concept in Latvian context, however there are still significant weaknesses and possible threats that are delaying development of the industry. There is non-estimated potential to cultivate seaweeds in Latvian conditions, therefore the overall preliminary analysis on techno-economic feasibility of seaweed biomass cultivation and its conversion system in Latvian context should be done.

Keywords: macroalage; seaweeds; seaweed conversion systems; biogas; the Baltic Sea; SWOT analysis; life-cycle cost analysis; LCCA

* Corresponding author.
E-mail address: jekaterina.krastina@rtu.lv

1876-6102
10.1016/j.egypro.2017.09.065

1. Introduction

The main objective of the concept of sustainability is to meet demand of burgeoning development and fast growing population for food, feed and energy and other needs in the best possible way while considering economic, social and environment aspects. The sustainable development concept has encouraged debate on looking towards to discover new sources to meet these needs. Oceans, seas and other water bodies have a reserve of such sources, as a result there is a rapidly growing literature and investigations on the potential of incompletely utilized aquaculture sources, largely macroalgae or most commonly seaweeds. Under the common name of seaweeds are considered incomputable species of macroscopic, multicellular marine plant-like organisms. Production of seaweeds is holding the capacity of different conversion roots and applications, such as human food and animal feed, biochemicals, bio-actives, bioremediation, bioenergy and biofuels, due to availability of various trace elements, minerals, vitamins and other biochemical elements, such as proteins, polysaccharides and less lipids with different application opportunities [1–3].

Due to huge diversity of total number of species, seaweeds are mainly categorized in higher level grouping based on pigmentation, such as Ochrophyta or brown algae, Rhodophyta or red algae, and Chlorophyta or green algae [4]. The total number of seaweed species is estimated with a degree of uncertainty at between 8,000 and 10,500 [4]. On logical grounds, there is compelling reason to argue that the capacity of seas and oceans in terms of seaweeds is not completely discovered yet.

Seaweed production, namely, cultivation and harvesting from wild stocks, is practiced in many countries and currently is a multi-billion industry [5]. Seaweeds are widespread around the globe at different sea depths. As a result on the whole at least 291 species are used worldwide from 43 countries, including 33 Clorophytes or green algae, 75 Ochrophyta or brown algae and Rhodophytes or red algae species [6]. Remarkable that the number of practiced species takes approximately 3 % share of the total number of seaweeds estimated to the present, which means that use of other seaweed species in the future can request more studies and investigations.

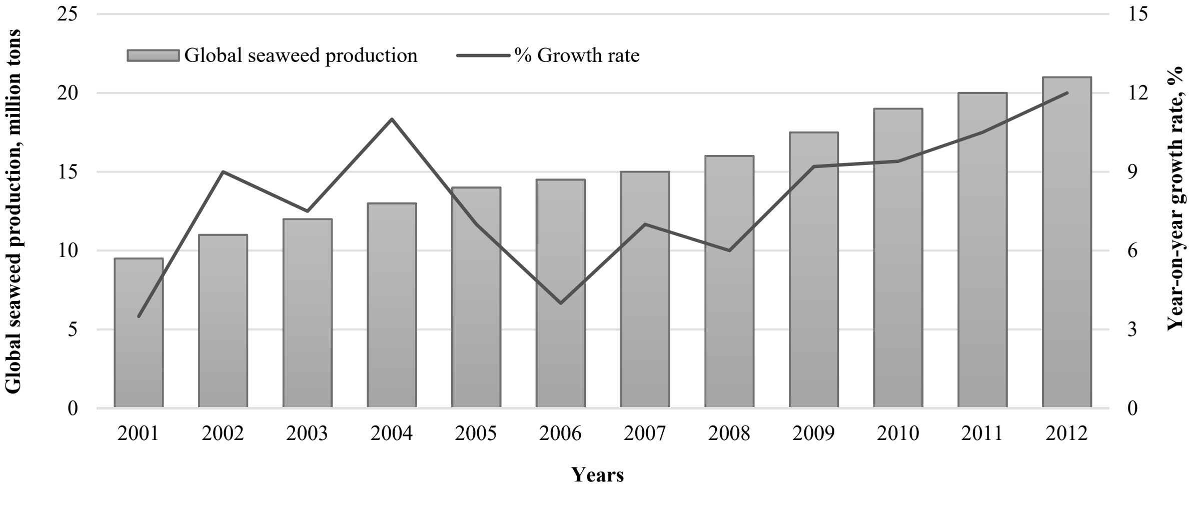

Fig. 1. World seaweed production and growth rate (year-on-year) [5].

Since 2001 the production of seaweeds has been systematically increasing with an average year-on-year growth rate of 8 % [7]. Taking into account production level of 2012 and ongoing growth in the seaweed farming activities, current production of seaweeds worldwide could be estimated more than 25 million t wet weight. However, seaweed production is mainly located in Asian region and just a small share is represented by European countries such as Norway, France, Ireland and Iceland, which are harvesting seaweeds from wild stocks [6]. It should be noted, that not all the countries which have direct access to the sea practice seaweed cultivation or harvesting. Indeed, Latvia is no exception and yet is not using such valuable source for different kind of end-products.

Latvia is a country in the Baltic region and has hundreds of kilometers (around 500 km) of shore along the Baltic Sea and the Gulf of Riga. In spite of such access to the sea, the only one main aquaculture form is practiced, namely, fisheries [8]. On this basis it can be suggested that other aquaculture forms have a great prospect in Latvian sea areas. There is non-estimated potential to cultivate seaweeds in Latvian conditions, therefore the overall preliminary analysis on techno-economic feasibility of seaweed biomass cultivation and its conversion systems in Latvian context should be done.

This study investigates potentials of seaweed biomass as a feedstock for biorefinery approach in Latvian context. The results of the analysis on the present situation and potentials will be used in the further work in conducting techno-economic feasibility study on seaweed cultivation and its proposed conversion system with Life-Cycle Cost Analysis (LCCA) framework in order to enable further development of the seaweed industry in Latvia.

2. Methodology

In order to identify potentials of seaweeds as a feedstock for biorefinery approach in Latvian context literature review on the most abundant seaweed species in the coastline area of Latvia resulting in SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis is done. SWOT analysis is a tool for strategic planning used for different cases, e.g. for analysis of various projects or organizations [9]. SWOT analysis methodology comprises brainstorming for analysis and positioning internal factors, i.e. strengths and weaknesses, and external factors, i.e. opportunities and threats, of analyzed object. By identifying the factors in these four groups, the basis for decision-making and planning strategies is obtained. The main advantage of SWOT analysis is its application simplicity and structuring a particular brainstorming session, whereas the main disadvantage results in no opportunity to rank significance of one factor versus another [9]. Nevertheless, SWOT analysis is an appropriate tool to address wide range of business issues and therefore is widely practiced.

3. Results and discussion

3.1. Abundant seaweed species in the coastline area of Latvia

The brackish Baltic Sea is a marginal environment with high rate of ecological differentiation for marine species [10]. The Baltic Sea is a shallow sea with an average depth of 60 m [11, 12]. Salinity is decreasing from the entrance to the inner part of the Sea, and near Latvia a level of salinity reaches only 4–6 psu, while oceans have salinity levels up to 30 psu [11, 12]. Salinity is one of the factors which influence algae diversity and growth rates. Due to low salinity of the Baltic Sea near Latvia diversity of seaweed species is very low. Another factor which affects survival and adaption of marine organisms, thus diversity, is a high level of eutrophication in the Baltic Sea. Eutrophication and pollution caused by the large amounts of nutrients have increased nitrogen and phosphorus concentrations as a result seaweed population growth is under a threat [11, 12]. Currently in Latvia there are no precise data on available seaweed species in the Gulf of Riga and the northern part of the eastern Baltic Sea. The data from Schubert et al. study [11, 12] on abundant seaweed species in Finland coastline, where are quite similar growing conditions, including salinity of 5,7 psu, has been used to estimate seaweed species found near Latvian coastline area. Thereby, in total near Latvian coastline there are abundant 17 seaweed species, including 4 brown algae (*Ochrophyta*), 9 red algae (*Rhodopyta*) and 4 green algae (*Chlorophyta*). Purina and Sprukte [8], Balina et al. [11, 12] argue that the most common species of these genera are *Fucus vesiculosus*, *Furcellaria lumbricalis* and *Ulva intestinalis*. Nevertheless, there are still no monitoring data neither on distribution on abundant seaweed species, nor on its amounts washed ashore. As it is commonly known seaweeds are growing attached to substrates and therefore their natural habitats are not located near to the coast. The information about distribution and habitats of seaweeds is crucial when considering its harvesting from the wild. However, this information can be useful also when considering to cultivate them in offshore farms in order to investigate growth rates and affecting factors, also for site selection. Currently, seaweeds washed out are considered as a waste, which is decreasing the recreational value of the coastline [8, 11–13]. Appearance of washed seaweeds on the coastline is not regular. Nonetheless, seaweeds washed out ashore can be collected and used as a feedstock, for example, for third generation fuel production or for other products taking into account its chemical composition and properties [11, 12]. In the Gulf of Riga the most commonly *Fucus vesiculosus* species are washed out, while in the Baltic Sea coast seaside of Kurzeme more often *Furcellaria lumbricalis* species

[14, 15]. Summarizing the estimation of abundant seaweed species in the coastline of Latvia it can be concluded that there are species that could be suitable for cultivation, and furthermore washed out ashore seaweed biomass is ready to be potentially exploited.

3.2. Potentials of seaweed cultivation and its conversion systems

Conducted SWOT analysis shows that in Latvian context there are considerable amounts of strengths and opportunities for seaweeds to be potential as feedstock for biorefinery concept, however there are still significant weaknesses and possible threats that are delaying development of the industry (see Table 1).

Table 1. SWOT analysis on potentials of seaweeds as a feedstock for biorefinery in Latvian context.

Strengths	Weaknesses
• Around 500 km of salty water coastlines (~6 psu) are available in Latvia for cultivation; • Abundant species, such as *Fucus vesiculosus, Furcellaria lumbricalis* and *Ulva intestinalis*; • No competition with arable land and fresh water use; • Seaweed cultivation provide various ecosystem services; • Washed out seaweeds can be processed not just considered as waste	• Currently Latvia does not have any industry or pilot project on seaweed cultivation/ processing; • Lack of pilot projects in other countries within the Baltic Sea region, thereby it is not possible to directly take over the experience; • No precise data on distribution of seaweeds, growth rates and their chemical characteristics; • Seaweed hatchery is needed (land use); • Licensing and permits (i.e. EIA procedure); • Technologies for seaweed cultivation, handling and storage are under development
Opportunities	**Threats**
• Seaweed based products and overall biorefinery concept; • Integration of seaweed biomass in the existing production schemes (i.e. biogas production); • Capital costs decrease by increasing scales; • Monitoring of washed out seaweeds; • Use of different cultivation methods; • Combination of other seawater uses (i.e. wind parks, incorporating seaweed into other aquaculture hatchery • facilities)	• Effect of seasonality can impact seaweed biomass yields and chemical composition, resulting in oscillating feedstock flows; • Energy extraction from seaweed biomass is considered to be more expensive than conventional fuels; • Public opposition for launching seaweed cultivation (recreational value decrease); • Protected territories (*Natura 2000*)

On the one hand, it is evident that Latvia has a broad access to salty water thus it is possible to establish seaweed cultivation site in many parts of Latvian coastline territory varying in size and used cultivation techniques in order to produce seaweed based products or even establish biorefinery concept, however there are no comprehensive estimates on abundant seaweed species and distribution of natural habitats, growth rates, changes to seasonality and their chemical characteristics. In addition, there is no data on washed out seaweed biomass which can be used for further processing, therefore that can be considered as opportunity to establish monitoring systems for reliable data obtaining. Furthermore, as strengths for seaweed cultivation can be considered no competition with arable land and various ecosystem services, including, cleaning of seawater from excess nutrients and CO_2, enhancing biodiversity and fisheries, and opportunities, such as reduction of costs by combination with other seawater uses (i.e. wind farms and other aquacultures) and by increasing scales of operation (unit costs).

On the other hand, there are significant constraints, including lack of pilot projects neither in Latvia nor in other countries within the Baltic Sea region, thereby it is not possible to directly take over the experience. Technologies for seaweed cultivation, handling and storage are under development. Effect of seasonality can impact seaweed biomass yields and chemical composition due to climate conditions, thereby no economic estimations on cultivation in such climatic conditions is possible yet. In addition, there can be constraint for site selection due to protected territories (*Natura 2000*) and public opposition for launching offshore seaweed cultivation. Furthermore a sort of licensing and permits should be obtained in accordance with Latvian legislation [17]. It should be noted, that currently there is no single procedure for obtaining a permit, therefore each case would be viewed individually [16]. It is expected that there would be a requirement to carry out an environmental impact assessment and the areas of existing restrictions, such as protected areas taken into account.

On the basis of SWOT analysis, it could be suggested that seaweeds as feedstock for biorefinery in Latvian context have a great prospective, however, for the development of the industry it is necessary to move towards from the general cultivation to the specific conversion roots of seaweeds. Applying of biorefinery approach to seaweed production and conversion allows to reduce waste, costs and obtain various algae based products. In addition, biorefinery concept is reasonable when considering seaweed value pyramid and end-markets, with energy and bioremediation being low value products and increasing for chemicals, food, feed and pharmaceuticals, in order of increasing value respectively [5]. Thereby the approach could allow to access different markets. In particular each possible use of seaweed biomass has different timescale to commercialization, if the proposed use is not at its mature phase [5]. Most commonly the low value products have the shortest timescale to commercialization [5], on this grounds biogas production within anaerobic digestion technology and fertilizer production as a by-product could be proposed for commercialization in Latvian context at first. This choice can be strengthened by the fact that biogas production is quite mature technology in Latvia. In 2014 the number of biogas plants operating in Latvia reached 54 [17]. In addition, by many researches anaerobic digestion was proposed to be the closest energy extraction method from seaweed biomass to industrial exploitation [18]. Methane yields from anaerobic digestion process from seaweed biomass have an estimation in the range of 0.14–0.40 m^3 kg^{-1} of volatile solids, but commonly 0.20 m^3 CH4 kg^{-1} [18]. Furthermore, biogas production has positive environmental aspects, which are extremely urgent in the current climate changing reality. Biogas production falls under the scope of multiple EU directives, including the main purpose of the Renewable Energy Directive (2009/28/EC). Promotion of production of the biogas based on seaweed biomass either for following use in cogeneration technologies (CHP plants) or upgrading for use as an alternative fuel for transport sector, can help the fulfillment of renewable energy 2020 targets.

4. Conclusions and way forward

At the moment as a potential seaweed conversion system in Latvian context is proposed biogas production from the most abundant seaweed species, *Fucus vesiculosus, Furcellaria lumbricalis, Ulva intestinalis,* respectively. In order to enable development of the seaweed industry in Latvia, further techno-economic feasibility study with Life-Cycle Cost Analysis (LCCA) perspective on proposed seaweed species cultivation and its conversion system to biogas and fertilizer as a by-product, should be directed at the following issues:

- Determination the properties of seaweed species, including, potential cultivation systems and yields (growth and methane);
- Estimation of potential amounts of washed out seaweed biomass (as an addition feedstock);
- Identification of various issues and barriers limiting or affecting the development of seaweed as aquaculture form and its further processing (including seasonality issues and permanent feedstock supply);
- Determination of possible cultivation site and CHP plant capacity and location;
- Estimating relevant life cycle costs and revenues of proposed seaweed cultivation site and processing system;
- Identification of legal aspects and regulation for seaweed cultivation (licensing and permit procedures);
- Determination of potential environmental and social externalities;
- Identification of bottlenecks and criticalities by sensitivity analysis.

It should be emphasized that, in spite of difficulties in estimation of environmental and social externalities, they should be taken into account, if possible monetized, in order to enhance environmental project competitiveness. NPV and other supplementary measures are proposed to be applied during LCCA study to assess cost-effectiveness of proposed seaweed biomass cultivation and conversion system, as well to identify bottlenecks and criticalities. Extent of the studiousness should be adjusted to the needs of the project. On these grounds, it should be noted that delimitation is critical, therefore aspects which are to be included and degree of detailing should be set. The conceptual supply chain for use of seaweeds to produce biogas includes the following phases:

- Seaweed cultivation (including hatchery and nursery procedures, deployment on sea installations, periodic monitoring);
- Harvesting;
- Transportation;

- Pretreatment (cleaning from inorganic matters and size reduction);
- Conversion (anaerobic digestion and CHP unit).

The seaweed production site will be modelled in order to annually supply with the feedstock for biogas production and further combustion in 0.5 MW CHP unit. Preliminary estimates shows that to ensure permanent CHP plant operation supply of approximately 40 000 $t \cdot yr^{-1}$ fresh seaweed biomass is required. It should be noted, that there could be difficulties with permanent seaweed biomass supply, thereby the use of other feedstock for co-digestion is additional subject for further techno-economic feasibility.

Acknowledgements

The work has been supported by the National Research Program "Energy efficient and low-carbon solutions for a secure, sustainable and climate variability reducing energy supply (LATENERGI)".

References

[1] Peng Y et al. Chapter 5 – Chemical composition of seaweeds. In Seaweed Sustainability; 2015.
[2] Balina K, Romagnoli F, Blumberga D. Chemical Composition and Potential Use of Fucus Vesiculosus from Gulf of Riga. Energy Procedia 2016;95:43–49.
[3] Elegbede I, Guerrero C. Algae Biofuel in the Nigerian Energy Context, 2016.
[4] Radulovich R et al. Chapter 3 – Farming of seaweeds. In Seaweed Sustainability; 2015.
[5] Capuzzo E, McKie T. 2016. Seaweed in the UK and abroad – status, products, limitations, gaps and Cefas role. p.66.
[6] White LW, Wilson P. Chapter 2 – World seaweed utilization. In Seaweed Sustainability; 2015.
[7] Rajauria G. Chapter 15 – Seaweeds: a sustainable feed source for livestock and aquaculture. In Seaweed Sustainability 2015;389–420.
[8] Purina I, Sprukte S. Juras teritorijas lietojuma veidi Zilas izaugsmes konteksta un to ietekme uz Latvijas teritorialo juras udenu vidi. Riga; 2015.
[9] Bohm A. The Swot Analysis. Munchen: GRIN Verlag; 2009.
[10] Bergstrom L. Macroalgae in the Baltic Sea – responses to low salinity and nutrient enrichment in Ceramium and Fucus. PhD Dissertation, Umea University; 2005.
[11] Balina K, Romagnoli F, Pastare L, Blumberga D. Use of Macroalgae for Bioenergy Production in Latvia: Review on Potential Availability of Marine Coastline Species. In: 23rd European Biomass Conference and Exhibition, Austria, Vienna, 1-4 June, 2015.
[12] Balina K, Romagnoli F, Pastare L, Blumberga D. Use of Macroalgae for Bioenergy Production in Latvia: Review on Potential Availability of Marine Coastline Species. Energy Procedia 2016;113:403–410.
[13] Balina K, Lika A, Romagnoli F, Blumberga D. Seaweed cultivation laboratory testing: effects of nutrients on growth rate of Ulva intestinalis. Energy Procedia 2016;113:454–459.
[14] Medne R, Purvina S. AQUABEST projekts un salsudens akvakultura Latvija. Inovativas pieejas un tehnologiju izmantosana ilgtspejigas akvakulturas attistibai Baltijas juras regiona 2013. Available: http://www.bior.gov.lv/lv/left-menu/petnieciba
[15] Baltijas Vides Forums. Juras telpiskais planojums Latvijas Republikas teritorialajiem un ekskluzivas ekonomiskas zonas udeniem; 2015. Available: https://jurasplanojumsdotnet.files.wordpress.com/2015/07/a-dala_paskaidrojuma-raksta-projekts2.pdf
[16] Vides attīstības biedrība. Submariner, 2013. Algu audzesana un parstrade – iespeja ilgtspejigai izaugsmei. Available: http://www.videsattistiba.lv/lv/projekti/submariner/jaunumi/aļģu-audzēšana-un-pārstrāde-iespēja-ilgtspējīgai-izaugsmei.html
[17] Biogas development in Latvia. Latvian Biogas Association; 2015. Available: http://latvijasbiogaze.lv/index.php
[18] Milledge JJ, et al. Macroalgae-derived biofuel: A review of methods of energy extraction from seaweed biomass. Energies 2014;7(11):7194–7222.