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THE POTENTIAL OF BALTIC SEA ALGAE AS AN AGRICULTURAL RESOURCE ENHANCING SUSTAINABILITY IN LATVIA

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Abstract
One of the main objectives for the Baltic Sea regions is the harmonisation of the economic development and environmental sustainability. The identification of knowledge-intensive bioeconomy as one of the primary fields of the strategy for smart specialization (RIS3) in Latvia indicates the transition to sustainable and climate neutral approach for the development of Latvia. The strategy aims to promote a more sustainable and efficient use of natural resources, to create high added value, to promote coordination of export and economic interests with environmental protection. This is a multi-faceted and complex process. A scientifically sound approach is needed to develop the most appropriate solutions. The article examines algae biomass as a potential for renewable resources in the agriculture of Latvia in the context of sustainability. The research is aimed at exploring the potential of the Baltic Sea algae as a sustainable agricultural resource in Latvia, focusing on its impact on cultivated plants during the study. The potential is being assessed by conducting a practical study in two stages. The results of the study confirm the potential use of Baltic Sea algae as an agricultural resource in Latvia, which requires further evaluation of the effect of the liquid digestate fraction on crop green mass to determine its potential applicability in agriculture using algal biomass.
Key words: algae, Baltic Sea, agricultural resource, sustainable development, Latvia.

Introduction

In the context of the knowledge-based bioeconomy (KBBE), the value chain includes the organization of economic activities connected to the bioeconomy sector, including the use of knowledge flow, innovation and the use of biomass circulation. The bioeconomy aims to create new value chains for the product groups that are traditionally based on non-renewable resources, for example, oil, natural gas, coal, chemical substances, etc. However, short-term profits and globalized production are often prioritized in the global value chains of the bioeconomy, which may hinder the use of biomass circulation. In order to achieve a sustainable and circular bioeconomy, traditional linear value chains (Kircher, 2021; Grinberga-Zalite & Zvirbule, 2022) need to be modified and adapted.

Rising attention is being paid towards the implementation of the circular bioeconomy principles across different value chains. The central element of bioeconomy is the formation of the integrated value chains and prevention of obstacles in the sectors, emphasizing the importance of sustainability controlled by value chains (Aggestam & Giurca, 2022).

The Ministry of Agriculture of the Republic of Latvia has proposed measures to solve problems in the agricultural sector, stressing the need for innovation, sustainability and efficient supply chains. These measures serve as an answer to several problems, including rising costs of production, low yield rate, shortage of manpower and uncertainty for future (OECD, 2019).

Addressing the issues of the agricultural sector requires an integrated approach in a multidisciplinary context. The purpose of this research is to analyze the potential of the Baltic Sea algae as a sustainable agricultural resource in Latvia and evaluate its impact on cultivated plants during the study. To achieve the purpose of the research, following tasks were drafted: 1) to characterise the use of algae a sustainable natural resource in the guidelines and the directions of previous research; 2) to sample macroalgae in the Latvian coastal area of the Baltic Sea region to determine the extent of leaching and to identify species suitable for agricultural use; 3) to conduct controlled experiments to assess the impact of Baltic seaweed as an algal digestate extract on seed germination and health in order to quantify the benefits.

Materials and Methods

In the theoretical discussion of the study on the role of algae as a potential agricultural resource for sustainable development in Latvia, 19 sources were analyzed using the monograph method. To establish the potential use of algae in the agriculture of Latvia, two laboratory evaluations were performed in collaboration with Latvia University of Life Sciences and Technologies and the laboratories of the Liepaja University. Both of these researches complement each other establishing validations and a succession of iteration processes, and reaching technologic readiness level TRL3/TRL4. The results of the research were collected by using qualitative and quantitative methods of analysis. Case study was performed by using laboratory analysis and experiments. Data from tests and experiments were grouped and analyzed in order to determine connection between the objects under research.

Results and Discussion

A Clean Planet for all is a long-term strategic vision of European Commission for a climate neutral economy that includes using algae (European Commission, 2018). *Blue Growth* of European Union (EU) is a long-term strategy to support sustainable growth in the marine and maritime sectors. The driving forces of the European economy are seas and oceans; thus, they have a huge potential for innovations and growth. One of the visions of the strategy – improvement of environment, publicly available bioproducts, ecoservices, building a favourable consumer position for the usage of algae (Johnson, 2018). Referring to the joint project of Kurzeme planning region, GRASS and INTERREG – an overview of the regulation of cultivation, collection and storage of macroalgae in Latvia, documentation information strategy for sustainable bioeconomy in Europe, EU strategies for the Baltic Sea region, correspond with the strategies and initiatives mentioned above (Kurzeme planning region, 2021). In *Latvian Bioeconomy Strategy 2030*, section under the Bioresources – Fisheries, states that: 'the sea biopotential that has not been used in Latvia so far, including seaweed, mussels, and algae which may be used, for example, in chemical and pharmaceutical industry' (Latvijas Republikas Zemkopības ministrija, 2018).

Algae to a large extent is an unused resource. Algae can be used to limit carbon footprint in production of food, feed, medicines, biodegradable plastics, fertilizers, growth stimulators, innovative products, biogas and biofuel. Most of the political documents approbate cultivation options for different kind of algae species in sea regions. This is a commendable action, because cultivation of algae does not compete with agricultural land (Lee, Noh, & Khim, 2020).

The topic of algae biomass use is also topical in other Baltic States and in the Baltic Sea region as a whole. The existing scientific research basis about the use of algae currently offers different research discourses, for example, a joint group of researchers from Estonia, Latvia, Poland and Germany evaluated the potential place of algae in the overall ecosystem and the created value chain in Eastern Baltic Sea region of Maritime Spatial Planning. These authors stress that cultivation of algae and further processing already exist in Europe, but there has been no social and spatial acknowledgement. This endangers the achieving of the sustainability goals, because they create interdisciplinary overlaying (Armoškaitė *et al*., 2021).

Since the 1940s algae has been a resource for producing hydrocolloid in Baltic states. Estonia is one of the Baltic states that has maintained this production to this day. This is affected by sustainability in production processes. The authors emphasize that it is essential to evaluate and search for solutions for minimizing non-sustainable algae production in the value chain (Weinberger *et al*., 2019).

Vytautas Magnus University researchers V. Vitunskienė, A. Aleksandravičienė, J. Čaplikas and A. Dapkuvienė have concluded that the potential of production of algae in Lithuania is being studied, especially for the production of biofuel and other bioproducts. Cultivation of algae in Lithuania include both traditional and innovative methods, for example, open pond systems and closed photobioreactors. The country's approach for algae cultivation is affected by geographic and climatic conditions, as well as its commitment to use sustainable and renewable energy resources. Regardless of the potential, cultivation of algae in Lithuania faces challenges such as the need for more efficient and profitable cultivation and harvesting methods. Nevertheless, the strong agricultural foundation of the country, availability of biomass and ongoing research on improvement of cultivation methods for algae open considerable options for the development of algae bioeconomy (Vitunskienė *et al*., 2023).

Whereas L. Pastare in her research underlines the positive environmental impact using a digestate (a by-product of biogas production) as a substitute for chemical fertilizers, it is concluded in the research that algae are a promising resource for sustainable energy production. However, additional research is necessary to solve the problems and optimize the respective processes (Pastare *et al*., 2014).

Hence the author concludes that the current scientific research basis about the use of algae in the Baltic states is diverse and covers various aspects starting from environmental impacts and ending with possible commercial usage. Although there are still imperfections in research that need to be prevented to comprehend and use alga potential fully in these regions taking into account interdisciplinary approach within the ecosystem.

In the first stage of the author's research, the potential of the renewable natural resource available in Latvia – algae – was evaluated in increasing the crop capacity of agriculturally cultivated plants. During the research macroalgae samples were collected in the Baltic Sea region across the seacoast of Latvia in 5 areas: Pate, Liepāja, Pāvilosta, Kolka and Mērsrags. The collection of samples is reflected in 'Figure 1'.

Figure 1. Sample collecting in Mērsrags.

25 samples were taken within polygons of 1 m x 20 m by footstep of five meters. Re-sampling was being performed in November of the same year in order to compare the seasonal change in algae composition. During the research algae washout volume was also determined. From Kolka to Engure it is little 0,1 m^3/100 m. On the West coast of the Gulf of Riga the volumes are increasing from the North to the South. During the summer washout volume of macroalgae on exposed parts of the coast in Pāvilosta is 17 m^3/100 m. In autumn, the washout volume of

macroalgae is 0 – 2.54 m^3/100 m, and in most cases, it is less than 1 m^3/100 m, except for Liepāja, where it reached the maximum of the season – 228 m^3/100 m. The collected biomass of algae was dried in the environment of laboratory and calculations were drawn about separate species and their dry weight (DW). The calculations about the drawn calculations of the separate species and the place of sample collection are summarized in Table 1. Crude ash substance was determined for the samples collected. In this case crude ash, on a provisional basis, indicate on samples more contaminated with sand particles or on the contrary the cleanest samples. The degree of grinding of the samples varied: fine, coarse, medium. On a provisional basis, the lowest admixture of sand particles was found in the coarsely grind samples collected in Liepāja, because the crude ash contents were the lowest. Both the algae species dominating in the sample, and the degree of grinding plays an essential role in the high degree of purity. The samples collected in Liepāja were dominated by *Furcellaria lumbricalis* that have less grains of sand on its surface and do not flatten when drying, the mass does not become dense. After grinding the samples, finer admixtures are easier to separate by sifting, but heavier ones can be separated using gravity. Samples from Liepāja and Pape, which have similar botanical composition and proportions of species, could not be ground to a powdered consistency as other samples by the methods used in the study. This may indicate potential issues in the selection of the aggregate state of the product and in the production process.

Table 1

Estimates of individual algae species at different sampling points in summer 2021, DW%

Genus	Species	Pape	Mērsrags
Cladophoraceae	*Cladophora glomerata*	0.0685	0.3085
Cladophoraceae	*Cladophora glomerata*	0.2458	0.1788
Cladophoraceae	*Ulva intestinalis*	0.0000	0.0805
Cladophoraceae	*Ulva prolifera*	0.0073	0.0982
Potamogetonaceae	*Battersia arctica*	0.0000	29.3100
Potamogetonaceae	*Elachista fucicola*	0.0004	0.1626
Potamogetonaceae	*Fucus vesiculosus*	0.0000	3.0521
Potamogetonaceae	*Ceramium virgatum*	0.0027	0.0055
Potamogetonaceae	*Coccotylus truncatus*	0.0343	0.6963
Potamogetonaceae	*Furcellaria lumbricalis*	13.1102	0.0000
Potamogetonaceae	*Vertebrata fucoides*	2.2861	0.1091

Source: author's calculations.

In order to determine the biomass potential of algae, it is necessary to determine the exchangeable acidity. The exchangeable acidity is determined by potentiometric manner, the methodology used for determining reaction in peat. The analysis was performed in two reruns for each version of the average samples. The obtained results indicate insignificant differences between the analysed versions; therefore, there is no need for in-depth repeated analysis by extracting more versions. The collected data demonstrate that algal biomass material has a weak acid reaction, which is optimal for use in most soils and crops in Latvia. About 40% of the soils are acidic and slightly acidic in Latvia (pHKCl<6.0), and the average soil pH is 6.2 (State Plant Protection Service of the Republic of Latvia, 2021). Algae contain macroelements and microelements, amino acids, vitamins, plant hormones – cytokinin, auxin (Craigie, 2011) and abscisic acid (Khan, 2009). The benefits of using algae and their products include stimulation of seed germination, increase yield growth, plant root growing, plant tolerance to various stress conditions, drought, high soil acidity) and promoting plant resistance to disease and attacks of pests (Eyras, Rostagno, & Defossé, 2013). There are many species of sea algae and their various extracts thereof that have been tested to contain various plant diseases and pests before they harm plants. Plant pathology studies have been showing positive results about the effect of induced resistance for plant defence system against pathogens by sea algae extracts (Pourakbar *et al*., 2021). Algae remedies are used for reducing abiotic or non-living natural factors created (temperature, water deficiency, increased EC) and biotic (caused by living organism pathogens) stress on plants (Tuhy, Saeid, & Chojnacka, 2020). Results of the first stage of the research and information available in theory suggest the potential of the algae species *Furcellaria lumbricalis* as a plant growth enhancer – a biostimulator.

The author's objective of the second stage of the research was to determine the algae species

Furcellaria lumbricalis impact as a biomass on sowing of the cultivated plants with anaerobic fermentation. At this stage, a prototype of algae extract was developed in laboratory conditions, involving several stages: (1) collection of biomass – 25 l of algae was manually harvested on February 6, 2022; (2) biomass pre-treatment – purified under laboratory conditions using 20 l container; (3) anaerobic fermentation – 25 l of algae was placed in a 30 l biogas fermentation plant in a container equipped with electric heating and thermostat (accuracy ± 0.5 °C) with a working temperature of 50 °C; (4) extraction of the liquid fraction of digestate – on February 20, 2022, the liquid fraction of digestate was strained manually, which ensured anaerobic fermentation of 14-day algal biomass. The first four steps of the second stage are graphically reflected in 'Figure 2' within the yellow border. Additionally, it reflects its possible adaptation to production conditions. Blocks outside the yellow border and resource flow biostimulator under the laboratory production process is not included, but indicate on possible use in production, drying, in ensuring bioreactor processes and the production of by-products. The biogas obtained during the production process is recommended to be used in order to maintain the processes of the production, for example, to use the electricity generated in the cogeneration plant for temperature control of the bioreactor, and the heat produced by the cogeneration plant – in drying of the algal biomass, in cases if there are remains of collected biomass after inserting in the production size bioreactor, so the remained algal biomass does not start decomposition process in the stall. For the production of biogas from macroalgae, the incorporation of *Furcellaria lumbricalis* has been carried out prior to the development of a prototype of algae extract. In the pilot study: *Production of biogas from sea algae and wine production waste* biogas extraction processes have been compared with and without identical setting of inoculum. Both experiments produced highly different amounts of biogas and methane content ratios that indicate the beneficial effects of winery residue on anaerobic fracturing of algal material. Respectively the experiment performed confirms that the fermentation system made of *Furcellaria Lumbricalis* algae detritus and wine production waste, is a promising project for biogas production. However, there is restrictive environmental and social aspect – sea algae detritus and inoculum seasonal availability (Zaimis, 2018). This aspect should be taken into account in the future development of sea algae products and is recommended to find the most suitable and available inoculum that will increase extraction of biogas and quality of the potential end product, and also would be suitable for use in agriculture, ensuring the products higher added value. (5) liquid fraction obtained is diluted in different concentrations: 12%, 6% un 3% and evaluation is being made on 320 seeds of cultivated plant basil in an automated greenhouse, where the plants are provided with steady and controlled growing conditions.

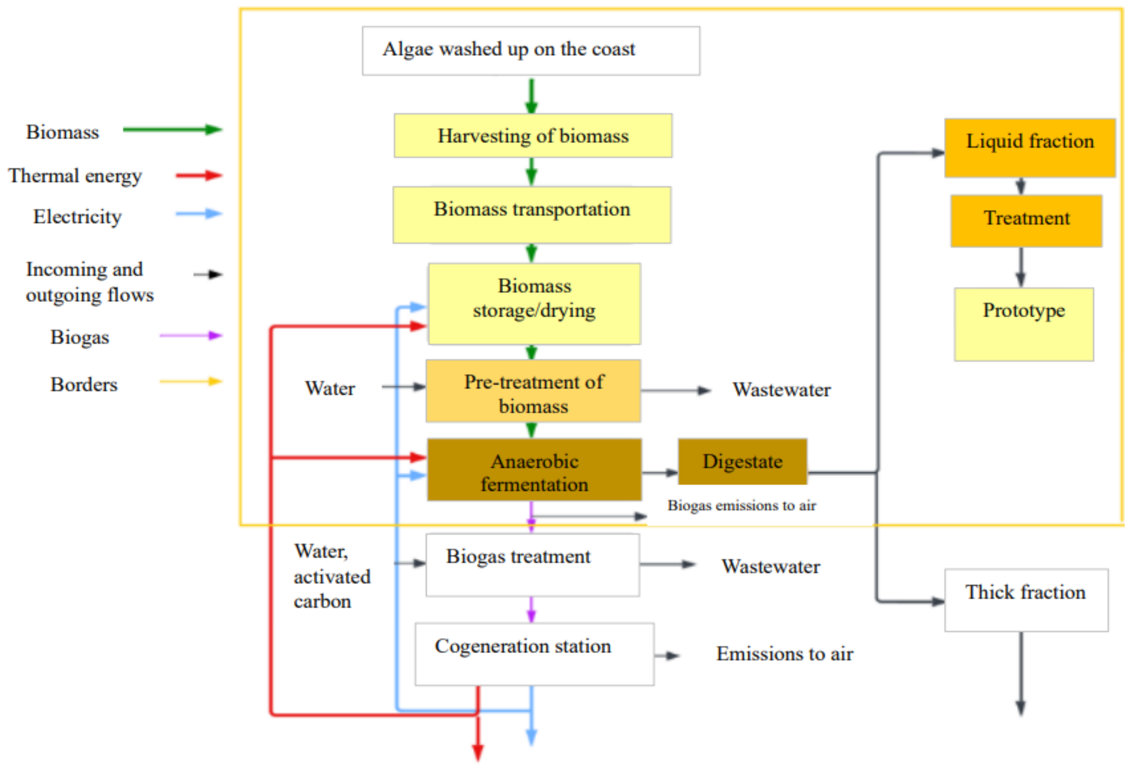

Figure 2. Entering and exiting resource flows for the production of prototype.

Observation data were registered, and data analysis was made by photo fixation method. The course of evaluation of initial impact on cultivated plants: 1) prepared plastic pots for seedlings, filling with equal amounts of substrate in each pot and precisely 8 seeds, in total 80 seeds for each concentrate, (2) prepared concentrates – 120 ml diluted on 1l of water (1:8) 12% concentrate, 70 ml diluted on 1l of water (1:14) 6% concentrate and 30 ml diluted on 1l of water (1:33) 3% concentrate. Samples of dilutions are reflected in ‘Figure 3’.

Figure 3. Liquid fraction of the diluted digestate.

30 seedling pots, each has 8 seeds, treated with the concentrates, 10 pots of seedlings for each concentrate test. 10 reference pots of seedlings that are not treated with the concentrate. The diagram of evaluation of initial impact on cultivated plants is pictured in ‘Figure 4’. (3) Once a week, pots of seedlings are treated with water and twice a month with concentrate of liquid fraction.

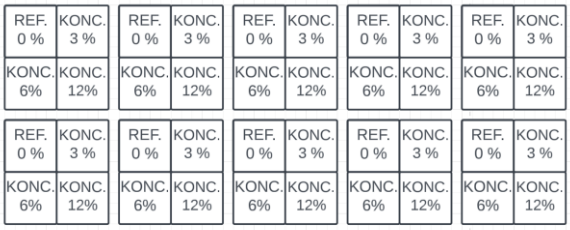

Figure 4. Chart of seedling pot setting. Each pot with 8 basil seeds, in total 320 basil seeds were used for the evaluation.

At the first time of data collection, i.e. 03.03.2023 the pots of seedlings that are treated with 12% of liquid fraction concentrate, seeds were sprouted most of all: 47 from 80, compared to other concentrates. The condition of seedlings on the first data collection can be viewed in ‘Figure 5’.

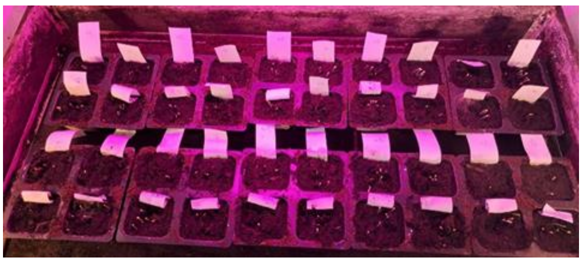

Figure 5. Progress of seed sprouting 03.03.2023.

At the second time of data collection, i.e. 06.03.2023 most growth of the seedlings was established on the pots of seedlings treated with 3% concentrates – 24 new sprouts in three days. The reference pots and pots of seedlings treated with 6% concentrate, approximate growth of 20 sprouts. Seedling pots treated with 12% concentrate showed the smallest growth – 5 sprouts. At the third time of data collection, i.e. 10.03.2023 the largest growth in seedlings is observed in the reference pots of seedlings – 9 sprouts. The second largest increase is observed in the seedlings of pots treated with 3% concentrate, with 5 new sprouts. The smallest growth in seedling pots treated with 6% and 12% concentrates – 4 to 5 sprouts. On 17.03.2023 seedling pots, excluding the reference pots (treated with water) were treated with the respective concentrate. At the fourth time of data collection, i.e. 24.03.2023 no change in the growth was observed in the seedlings of pots treated with 3% concentrate. Growth is observed in the reference pots with 2 new sprouts. New sprouts continued to grow in the seedlings of pots treated with 6% and 12% concentrates of liquid fraction. The condition of seedlings on the fourth data collection can be viewed in ‘Figure 6’.

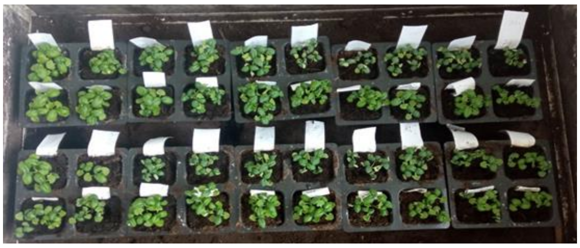

Figure 6. Course of seed germination in the seedling pots 24.03.2023.

After 29 days since the seeding, the fixed data were collected and summarized in Table 2. Pots of seedlings treated with 12% concentrate showed the fastest growth rate at the beginning of the evaluation and the largest number of sprouts at the end of the evaluation – 78.75%.

Table 2

The evaluation results of the initial impact on cultivated plants (basil) in 2023

Prototype %	03.03. pcs	06.03. pcs	10.03. pcs	24.03. pcs	Germination power %
0	32	51	60	62	77.50
3	25	49	56	56	70.00
6	29	51	56	60	75.00
12	47	52	56	63	78.75

Source: author’s calculations.

The reference pots of seedlings treated only with water, with no added liquid fraction, showed the second-best results of sprouted seedlings at the end of the evaluation. The rate of germination was steady during the whole time of evaluation. Germination percentage rate is 1.25% lower. It should be taken into account that the evaluation was performed on a small scale, the percentage difference is expected to be higher when scaling the experiment. The data obtained in the seedling pots treated with 6% concentrate are lower than the reference seedling pots, germination of seeds was steady. At the end of the evaluation the smallest growth of seeds was observed in the seedling pots treated with the 3% concentrate compared to higher concentrations of the liquid fraction; however, there was an interesting growth pattern – the seedlings sprouted later than seedlings in the pots treated with 6% and 12% concentrates. Following the initial evaluation, it can be concluded that the use of the 12% concentrate accelerates germination of seeds in the beginning stages, which cannot be said about the use of the 3% and 6% concentrates. This means that the visible effect of the liquid fraction prototype, according to the current data, works from the use of 12% concentrate. It should be noted that it is not clear to what extent the concentrate affects the volume of green mass of the plant over a longer period of time. It is positive that plants that are treated with liquid fraction concentrates of 3%, 6% and 12% have a visually higher stress resistance to drought before watering. The treated plants are not visibly wilted, whereas plants in the reference seedling pots are evidently wilted.

Conclusions

1. The author's analysis of theoretical literature confirms that the main problems currently arise from the use of non-renewable resources in harmonizing economic development and environmental sustainability in Latvia. Conversely, Baltic Sea algae is a largely untapped renewable resource whose potential studies are topical in order to move towards achieving the climate neutrality objectives. There is a research gap about circular economy-based use of algae with an integral approach of the bioeconomy to the overall ecosystem in order to exploit the full potential of the value chain in creating the added value.
2. Empirical studies carried out by the author in 2 stages acknowledge that on the Kurzeme coast of the Baltic Sea the algae species according to calculated data *Furcellaria lumbricalis* shows the second highest dry weight potential of 13.11 DW%, have less grains of sand on its surface and do not flatten and have low acid reaction, which is optimal for use in most soils of Latvia, with a wider probability of aggregate state when being commercialised.
3. Experiments conducted in the study on crop seeds indicate that 12% digestate liquid fraction concentrate delivers faster germination versus the 3% versus 6% concentrates. Overall germination rate for 12% concentrate versus 3% concentrate is 12.5% higher, but versus 6% concentrate is higher for 5%. Whereas visual observations show that plants treated with 3%, 6% and 12% digestate liquid fraction increase resistance to drought.
4. In reference to the obtained data in the empirical research, the author sees the perspective in future studies to evaluate the impact of the liquid fraction of digestate on the green mass of cultivated plants in order to determine its potential use in agriculture using algae biomass.

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References

Aggestam, F. & Giurca, A. (2022). Implementing circular-bioeconomy principles across two value chains of the wood-based sector: A conceptual approach. *Land*. 11(11), 2037. DOI: 10.3390/land11112037.

Armoškaitė, A., Bārda, I., Andersone, I., Bonnevie, I. M., Ikauniece, A., Kotta, J., Kõivupuu, A., Lees, L., Psuty, I., Strāķe, S., Sprukta, S., Szymanek, L., von Thenen, M., Schrøder, L., & Hansen, H. S. (2021). Considerations of use-use interactions between macroalgae cultivation and other maritime sectors: An eastern Baltic MSP case study. *Sustainability.* 13(24), 13888. DOI: 10.3390/su132413888.

Craigie, J. S. (2011). Seaweed extract stimuli in plant science and agriculture. *Journal of Applied Phycology.* 23:371–393. DOI: 10.1007/s10811-010-9560-4.

European Commission. (2018). *A Clean Planet for All. A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy.* Retrieved February 9, 2024, from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0773.

Eyras, M. C., Rostagno, C. M., & Defossé, G. E. (2013). Biological evaluation of seaweed composting. *Compost Science & Utilization*. 6(4), 74–81. DOI: 10.1080/1065657x.1998.10701943.

Grinberga-Zalite, G. & Zvirbule, A. (2022). ESG Investing Issues in Food Industry Enterprises: Focusing on On-the-Job Training in Waste Management. *Social Sciences.* 11(9), 424. DOI: 10.3390/socsci11090424.

Johnson, K. & Dalton, G. (2018). *Building industries at sea: 'Blue growth' and the new maritime economy*. River Publishers.

Khan, W., Rayirath, U. P., Subramanian, S., Jithesh, M. N., Rayorath, P., Hodges, D. M., Critchley, A. T., Craigie, J. S., Norrie, & J. Prithiviraj B. (2009). Seaweed extracts as biostimulants of plant growth and development. *Plant Growth Regul*. 28, 386–399. DOI: 10.1007/s00344-009-9103-x.

Kircher, M. (2021). Bioeconomy – present status and future needs of industrial value chains. *New Biotechnology.* 60 (Elsevier), 96–104. DOI: 10.1016/j.nbt.2020.09.005.

Kurzeme planning region. (2021). *Apskats par makroaļģu audzēšanas, vākšanas un uzglabāšanas regulējumu Latvijā* (Overview of the regulation of macroalgae cultivation, collection, and storage in Latvia). Retrieved January 16, 2024, from www.kurzemesregions.lv. (in Latvian).

Lee, K. H., Noh, J., & Khim, J. S. (2020). The Blue Economy and the United Nations' sustainable development goals: Challenges and opportunities. *Environment international*. 137, 105528. DOI: 10.1016/j.envint.2020.105528.

Ministry of Agriculture Republic of Latvia. (2018). *Latvian Bioeconomy Strategy 2030*. Retrieved January 16, 2024, from https://www.zm.gov.lv/lv/latvijas-bioekonomikas-strategija.

OECD. (2019). *Innovation, Agricultural Productivity and Sustainability in Latvia, OECD Food and OECD Library*. Retrieved January 16, 2024, from https://www.oecd-ilibrary.org/sites/dfffce93-en/index.html?itemId=%2Fcontent%2Fcomponent%2Fdfffce93-en.

Pastare, L., Romagnoli, F., Lauka, D., Dzene, I., & Kuznecova, T. (2014). Sustainable use of macro-algae for biogas production in Latvian conditions: A preliminary study through an integrated mca and lca approach. *Environmental and Climate Technologies*. 13(1), 44–56. DOI: 10.2478/rtuect-2014-0006.

Pourakbar, L., Moghaddam, S. S., Enshasy, H. A. E., & Sayyed, R. Z. (2021). Antifungal Activity of the Extract of a Macroalgae, *Gracilariopsis persica*, against Four Plant Pathogenic Fungi. *Plants*. 10(9), 1781. DOI: 10.3390/plants10091781.

State Plant Protection Service of the Republic of Latvia. *Outcomes of Soil Monitoring in 2021*. Retrieved February 12, 2024, from https://www.vaad.gov.lv/lv.

Tuhy, Ł., Saeid, A., & Chojnacka, K. (2020). *Algae Fertilizers*. In: Encyclopedia of Marine Biotechnology; John Wiley & Sons Ltd., Hoboken: NJ, USA. DOI: 10.1002/9781119143802.ch5.

Vitunskienė, V., Aleksandravičienė, A., Čaplikas, J., & Dapkuvienė, A. (2023). The strategic concept for the Lithuanian bioeconomy: Insights for niche bioenergy sectors. *Open Research Europe.* 3:101. DOI: 10.12688/openreseurope.16085.2.

Weinberger, F., Paalme, T., & Wikström, S. A. (2019). Seaweed resources of the Baltic Sea, Kattegat and German and Danish North Sea coasts. *Botanica Marina*, 63(1), 61–72. DOI: 10.1515/bot-2019-0019.

Zaimis, U., Jurmalietis, R., & Jansone, A. (2018). Processed seaweed and winemaking waste co-fermentation for biogas extraction: pilot study. *Engineering for Rural Development*, 1916-1919. DOI: 10.22616/ERDev2018.17.N497.