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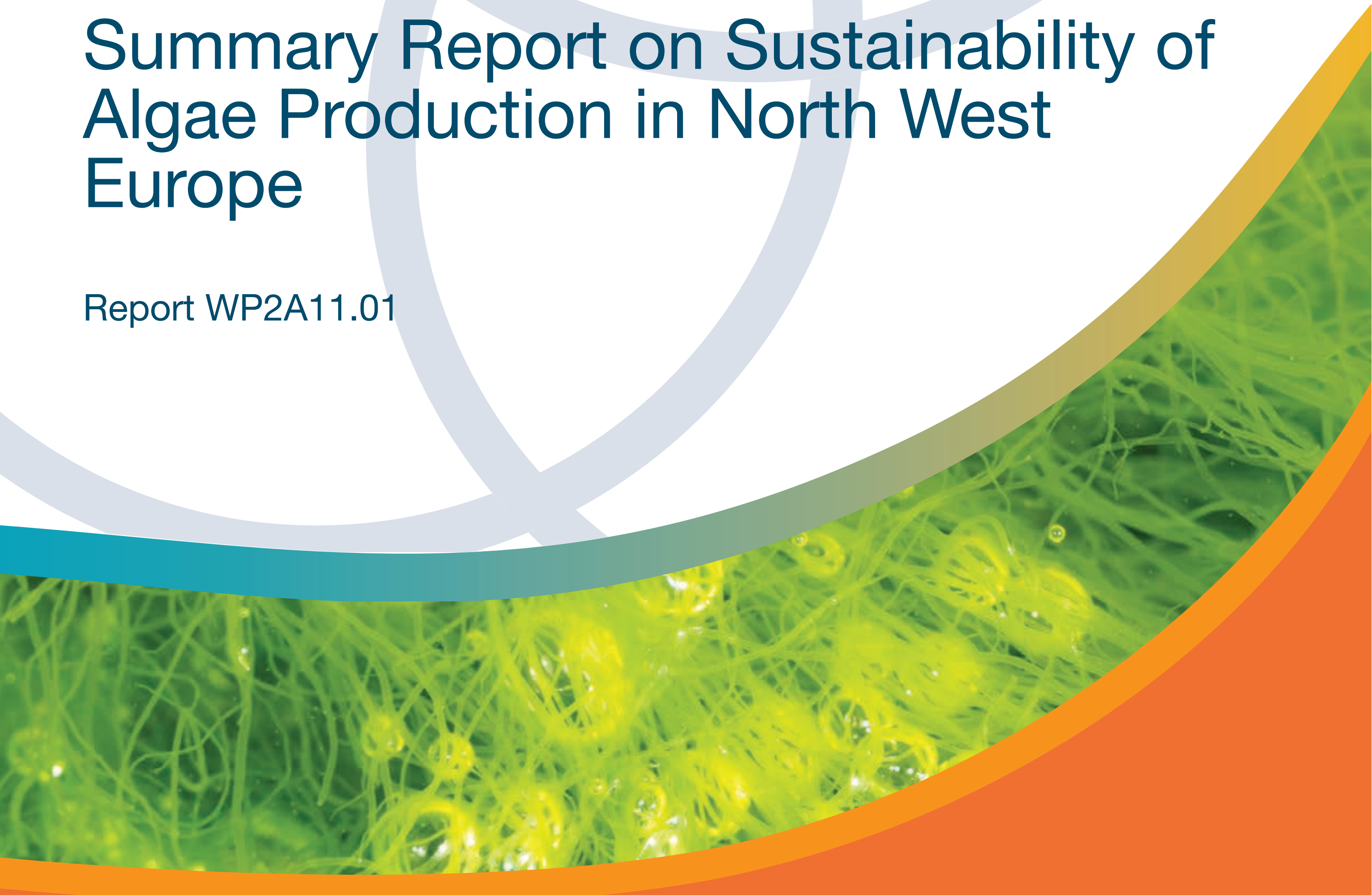
Summary Report on Sustainability of Algae Production in North West Europe

Report WP2A11.01



Energetic Algae ('EnAlgae')

Project no. 215G

Public Output

WP2A11.01 – Summary Report on Sustainability of Algae Production in North West Europe

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Please cite this document as follows:

Skarka, J., Rösch, C. & Kugler, F. 2015. *Summary Report on Sustainability of Algae Production in North West Europe*, Public Output report WP2A11.01 of the EnAlgae project, Swansea, December 2015, 9 pp. Available online at http://www.enalgae.eu/public-deliverables.htm.

This document is an output from the Energetic Algae ('EnAlgae') project, which has received European Regional Development Funding through the INTERREG IVB NWE programme.

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Summary Report on Sustainability of Algae Production in North West Europe

Contents

1 Introduction ... 3
  1.1 Methods ... 3
  1.2 The investigated pilot plants ... 3

2 Summary of the results ... 4

3 Main conclusions and the way forward ... 6
  3.1 Microalgae ... 6
  3.2 Seaweeds ... 7

References ... 8

Summary Report on Sustainability of Algae Production in North West Europe

1 Introduction

The aim of Action 11 within the EnAlgae project was to assess the sustainability of different algae process chains in North West Europe (NWE). This was accomplished by performing environmental life cycle assessment (LCA) case studies for the EnAlgae pilots using real data provided by the pilots. Furthermore, sustainability beyond the results of the environmental LCA was assessed qualitatively with the help of stakeholder workshops. An economic assessment of algae cultivation and processing was performed in Action 7 and is thus not included in this report but can be found in the corresponding Action 7 reports.

This report summarizes the results of the case studies and the stakeholder workshops and provides overall conclusions and recommendations on sustainability of algae production in NWE. A short description of the methodology and the investigated pilots is given in the next sections. Detailed information as well as detailed results and specific conclusions can be found in the case study reports and stakeholder workshop reports of Action 11 (Kugler et al., 2015a-d; Taelman and Sfez, 2015; Rösch et al., 2014a-b).

1.1 Methods

To assess the environmental sustainability the LCA method was used as a tool to quantify all relevant emissions and resources consumed, as well as the related environmental impacts and resource depletion associated with a product's life cycle. LCA takes into account the entire lifecycle: from the extraction of resources, through production, use, recycling, to disposal of the remaining waste (Rebitzer et al., 2004). For quantifying the life cycle impacts the ReCiPe method (Goedkoop et al., 2013) which covers a broad range of environmental impacts, e.g. climate change or human toxicity, and the CEENE method (Dewulf et al., 2007, Alvarenga et al., 2013, Taelman et al., 2014) which provides resource footprint through quantification of resources based on their exergy content, were used.

For the stakeholder workshops the World Café method (Brown and Isaacs, 2005) was applied as a simple, effective, and flexible format for group dialogue of participants with individual perceptions on benefits and risks from biomass production with microalgae or seaweeds. Participants were randomly divided into mixed groups à five persons and one person for each group was selected for documentation and presentation of the results of the group discussion. The discussion was structured along questions provided before the workshop together with some background information to introduce the participants into the topics for discussion. It was expected to get a broad spectrum of views and opinions, since stakeholders from industry, NGOs as well as from governmental institutions from different countries were invited.

1.2 The investigated pilot plants

Within action 11 five microalgae pilot plants and three seaweed cultivation pilots have been investigated. For the microalgae systems the final products have been biogas and/or different animal feed, partly in combination with waste water treatment. The seaweed process chains had biogas or biomass as a final product which could potentially be used as feedstock for biofuel production. Table 1 gives an overview of the investigated systems. The data used for the LCA came from the pilots for the process of algal biomass production and in cases where no data were available from the ecoinvent 2.2 database for modelling the conversion of algal biomass to biogas for reasons of comparability.

Table 1*: Investigated system setup of the EnAlgae pilot facilities. WWT: waste water treatment is integrated in the system. SU: Swansea University; htw saar: Hochschule für Technik und Wirtschaft des Saarlandes; InCrops: InCrops Enterprise Hub; UGent: Ghent University, Campus Kortrijk; WUR: Wageningen UR / ACRRES; NUIG: National University of Ireland, Galway; CEVA: Centre d'Etude et de Valorisation des Algues; QUB: Queen's University Belfast.*

Pilot	Algae	Cultivation system	Product system	Report
SU	Microalgae	Tubular photobioreactor	Biogas (WWT)	Kugler et al., 2015a
InCrops	Microalgae	Tubular photobioreactor	Biogas (WWT)	Kugler et al., 2015b
htw saar	Microalgae	Tubular photobioreactor	Biogas	Kugler et al., 2015c
UGent	Microalgae	Open pond, MaB-flocs	Shrimp feed (WWT)	Taelman and Sfez, 2015
WUR	Microalgae	Open pond	Animal feed	Taelman and Sfez, 2015
QUB	Seaweed	Longlines	Biogas	Kugler et al., 2015d
NUIG	Seaweed	Longlines	Biomass	Taelman and Sfez, 2015
CEVA	Seaweed	Raft system	Biomass	Taelman and Sfez, 2015

2 Summary of the results

In the following, the results are summarized for the three groups of algae process chains:

1. Microalgae production in closed photobioreactors and biogas as valorization path,
2. Microalgae production in open ponds and non-energetic valorization (e.g. animal feed), and
3. Seaweed biomass production in coastal waters with biomass or biogas as final product.

For the interpretation of the results it is important to notice that the data for the LCA was obtained from very small scale operations (i.e. the EnAlgae pilots). These small scale systems which are still under development have been compared with large scale and well established reference process chains, e.g. production of natural gas or soy beans.

The LCA results of the pilots that cultivated microalgae in tubular photobioreactors in a greenhouse coupled with biogas as valorization path showed that the environmental impacts were much higher than for the fossil reference (natural gas) (Kugler et al., 2015a-c). The most important contributor for these results was the high electricity demand for pumping the culture medium. The environmental impacts of the construction materials used also played an important role. Fertilizer use had only a small impact on total results and correspondingly the use of waste water instead of artificial fertilizer could only slightly improve the results.

More promising results have been obtained from the cultivation of microalgae in open pond systems to produce algae for use as animal feed or for waste water treatment and valorize the algal biomass as shrimp feed or biogas (Taelman and Sfez, 2015). However, these algae process chains at pilot scale still show higher environmental impacts compared to the conventional process chains soy bean production and shrimp feed production together with waste water treatment. Similar to the tubular photobioreactors the main reason for these results was the high electricity demand during the cultivation process for gassing and stirring of the culture medium. The case studies clearly show that the non-energetic valorization paths (animal feed, shrimp feed) have lower environmental impacts than the valorization as biogas to produce energy. Furthermore, the case study on waste water treatment and shrimp feed production with algae shows that up-scaling of the process has the potential to significantly reduce the environmental impacts.

The results of the LCA for seaweed cultivation with biogas as valorization path showed better results than for biogas from microalgae but still perform worse than the fossil reference (Kugler et al., 2015d). This was mainly due to high fossil energy consumption during the hatchery process and the offshore cultivation but also due to the demand for construction materials like steel and concrete. If only the seaweed biomass was regarded the results indicate that, depending on the location, the environmental impacts are in some cases comparable with those of terrestrial plants (Taelman and Sfez, 2015). Regarding the whole life cycle, less land resources are used for seaweed production compared to terrestrial plants since mainly marine surfaces and sea water are used in the cultivation step. Thus, seaweed has the potential of avoiding competition for land and fresh water. However, more fossil resources are needed for seaweed production than for terrestrial plants.

A summary of the results of the stakeholder workshops on microalgae (Rösch et al., 2014a) and seaweeds (Rösch et al., 2014b) can be found in table 2. For microalgae questions related to land use, CO_2 application from flue gases, energy balance, water use and genetically modified microalgae have been discussed. In the seaweed workshop one important issue was the ecosystem service that could be provided by the offshore cultivation of seaweeds. It was generally stated that a potential benefit could be coupled with a risk for the ecosystem. For example, the bioremediation potential of seaweeds could also lead to competition with the initial primary biomass production leading to a change of the ecosystem and biodiversity. The competition of new seaweed farms to existing industrial and other uses turned out to be an important obstacle. Particularly fishermen are in strong opposition to new seaweed farms as they fear negative effects on commercial fisheries.

Table 2*: Summarized results of the stakeholder workshops on microalgae (M) and seaweeds (S) using the integrative concept of sustainability (Rösch and Maga, 2012) as an analytical framework.*

Principle	Criteria	Stakeholder perceptions
Sustainable use of renewable resources	Land use	• Microalgae production preferably on marginal land (M) • Fertile land to be used for high value products only (M)
	Water resources	• Water demand should gain more attention (M) • Optimization for efficient energy and water use systems since energy and water savings are not contradictory (M)
	Impact on biodiversity	• Nursery and habitat function of seaweeds (S)
Sustainable use of the environment as a sink	Algal fuel-related GHG emissions	• There should be no difference whether the CO_2 demand for microalgae cultivation is covered by fossil or biogenic sources (M)
Avoiding technical risks with potentially severe impacts	Ecosystem changes	• Only native species should be cultivated (S) • Genetically modified (GM) algae should not be used due to inherent risks associated with their cultivation (M, S) • Exceptions for controlled production of GM algae for pharmaceutical products (M) • Seaweed is ambiguous regarding ecosystem changes (e.g. bioremediation vs. nutrient competition) (S)
Conservation of social resources	Attitude towards technology	• Competition to existing industry and uses (S) • Opposition of stakeholders, e.g. fishermen (S)

3 Main conclusions and the way forward

The overall results clearly show that with the technology used in the EnAlgae pilots an energetic valorization of the algal biomass is an unfavourable option from a sustainability point of view. This is mainly due to the high fossil energy demand during the algae cultivation process which is the dominating factor for most of the different environmental impacts. This applies to microalgae as well as to seaweeds, Alternative valorization paths, e.g. animal feed, turned out to be more promising. However, also in this case further improvements regarding the energy demand are needed to make algae competitive compared to established process chains and to reduce the environmental impacts. From a sustainability point of view, it is therefore recommended that future research should focus on non-energetic valorization paths of algal biomass.

3.1 Microalgae

In general higher biomass yields would lead to a reduction of the environmental impacts. However, it is important to notice that yields cannot be increased infinitively and are limited by the laws of thermodynamics and the maximum photosynthetic efficiency. Genetically modified microalgae are often discussed as a measure to increase biomass yield or the yield of desired products but the stakeholder workshop revealed a clear opposition against the use of GM algae to avoid inherent risks associated with their large scale cultivation. Furthermore, for microalgae higher yields are often related to a higher energy input because of a higher demand for mixing or gassing of the culture medium (Weiss, 2015). Thus, reducing the energy input seems to be more promising and has a higher potential for reducing the environmental impacts.

For microalgae substantial reductions of the direct energy demand are needed, especially for closed photobioreactors. In the case of the EnAlgae pilots with closed systems it could be observed that the equipment for pumping and gassing was often too powerful for the small scale operations. Thus, improvements can be expected if correctly scaled and balanced equipment would be used. Process optimization leading to lower gassing rates and flow velocities also have the potential to reduce the electricity demand. The electricity demand could be further reduced by changes in the design of the photobioreactor, e.g. tube diameter, or the design of the open pond and its stirring system (Taelman and Sfez, 2015). Changes regarding the process management, e.g. continuous production instead of batch mode, would be beneficial, as well. In general, the energy efficiency of all processes along the process chain has to be increased.

One important reason for the unfavourable results was the small scale of the EnAlgae pilots. For the very small pilots with tubular photobioreactors theoretical upscaling approaches have not been suitable. However, for the case study of the MaB-floc system (Taelman and Sfez, 2015) it could be shown that upscaling of the system would lead to significant reductions regarding the environmental impacts mainly due to reduced electricity consumption. This could also be expected for the other systems. This leads to the conclusion that more demonstration scale facilities are needed that could provide the data for future LCAs to get a more realistic picture of the environmental impacts of microalgal technology. Additionally the case studies showed that if electricity consumption is reduced substantially the materials used for the construction of the facilities become more and more important. In this regard benefits could also be expected via up-scaling of the system but also changes in the systems design or the use of other materials with less environmental impacts could lead to improvements.

As soon as the electricity demand is reduced the demand for nutrients and water will play a more important role regarding the environmental impacts. The use of waste water suitable for microalgae cultivation is an option to lower the demand for nutrients and freshwater. To further improve the sustainability of microalgae production highly integrated systems are the way to go. The combined waste water treatment with valorization of the microalgal biomass as shrimp feed already showed promising results (Taelman and Sfez, 2015). Another concept presented within the EnAlgae project was a closed microalgae production system integrated in the bioremediation scheme of a recirculating aquaculture system together with the production of high value products (eicosapentaenoic acid (EPA) with *Nannochloropsis salina*) and anaerobic digestions of the residual biomass (Kugler et al., 2015c). A further interesting concept was the use of microalgae for waste water treatment, anaerobic digestion of the biomass, and valorization of the digestate as soil conditioner and fertilizer (Kugler et al., 2015a). However, the environmental viability of the two latter concepts still has to be evaluated.

Another possibility for reducing the demand for fossil fuels and improve the carbon footprint would be the use of renewable resources for electricity supply to the algae production systems. However, as long as the energy demand of algae technology is still high this strategy would reduce the environmental impacts only at first sight. Algae should then be regarded as a technology for the conversion of energy instead of the generation of energy and the reference systems or the functional unit have to be adapted to obtain meaningful results. Furthermore, the stakeholder workshop on microalgae revealed that the conversion of “clean” renewable energy into algal biomass could be perceived as a “dirty trick” by the public.

Since it is often subject of discussion (Rösch et al., 2014a; Sayre, 2010) it should be stated here that regarding the greenhouse gas balance current microalgae technology is not suitable as a carbon capture and storage technology because of the high fossil energy demand needed for their cultivation leading to more CO_2 emissions related to the upstream process chains of electricity production than captured by the algae. However, microalgae technology can be regarded as a carbon capture and usage technology that converts CO_2 waste streams into valuable products. At the same time the use of industrial grade CO_2 usually needed for algae cultivation is avoided.

An advantage of microalgae is that non-arable land can be used for their production. There was a broad consensus on the stakeholder workshop that first of all non-arable land should be used for microalgae production. As an exception, the stakeholders indicated that microalgae cultivation on fertile arable land could be accepted by the public if high value products are produced. However, the impacts on biodiversity through the transformation of land into a large scale microalgae production site are unknown and research is needed in this field. Issues related to land use changes induced by microalgae cultivation should therefore be included in regional planning processes to address these concerns.

3.2 Seaweeds

For seaweeds a reduction of the environmental impacts related to the input of fossil energy could be accomplished by reducing the fuel used for sea transport (Taelman and Sfez, 2015). Here it is key to minimize the distance between the hatchery and the sea farms. Furthermore improvements related to up-scaling can be expected: the capacity of the hatchery would then better match with the sea farms (Kugler et al., 2015d) and sea transport would be more efficient due to more seaweed shipped per km. To reduce the electricity demand of the hatchery LEDs could be used for lighting and a better insulation of the hatchery would reduce the cooling demand (Kugler et al., 2015d). As the materials used for seaweed cultivation also play an important role a reduction of the material input or the use of alternative materials would lead to a reduction of the environmental impacts (Taelman and Sfez, 2015, Kugler et al., 2015d). As an example, the concrete anchors could be replaced by meshed nets filled with stones which would reduce the environmental impacts related to concrete production and at the same time could have positive effects on biodiversity.

Another possibility for improvements could be a change in harvesting practice (Rösch et al., 2014b): instead of completely harvesting the seaweed it could also be just cut back after six months. After a regeneration period a second harvest can occur. This would increase the yearly biomass yield and could thus lead to better results despite an increased need for boat transportation but the impact of the hatchery would be reduced.

The stakeholder workshop on seaweeds (Rösch et al., 2014b) revealed a number of open research questions related to sustainability. To get a more accurate picture of the effect of (large scale) seaweed cultivation on the marine ecosystem more research is needed addressing these questions. Similar to microalgae production, integrated systems for seaweed cultivation, namely the integrated multi-trophic aquaculture (IMTA), are promising concepts to increase the overall sustainability of seaweed cultivation.

Competition to existing users of the marine surfaces near the coast and opposition of stakeholders, fishermen in particular, turned out to be crucial for the future of seaweed cultivation in NWE. To ensure the development of a sustainable seaweed industry opposed stakeholders have to be involved in future planning processes and have to be informed about potential benefits of seaweed cultivation for their own business. Successful model projects that show how stakeholders can be integrated in the decision and planning processes for a new seaweed site and also show the resulting benefits for the stakeholders could help for a higher acceptance.

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Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

INTERREG IVB

EnAlgae is a four-year Strategic Initiative of the INTERREG IVB North West Europe programme. It brings together 19 partners and 14 observers across 7 EU Member States with the aim of developing sustainable technologies for algal biomass production.

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