Assessing the utilisation of duckweed

Development of a new protein value chain

A thesis presented for the degree of
Operations and Management Engineering

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Summary - Dansk

Dette speciale er skrevet for civilingeniøruddannelsen, Operations and Management Engineering, på Aalborg Universitet. Det er udarbejdet i samarbejde med startupvirksomheden BioMend. BioMend er en startup, der forsøger at udarbejde en økonomisk bæredygtig løsning, der kan oprense nærringstoffer fra spildevand på bl.a dambrug.

Dette speciale analyserer og udarbejder en løsning der fokuserer på den potentielle værdikæde, som andemad indgår i. Denne værdikæde består af høsten samt udnyttelse af andemad som bioresource.

Metoden er en pragmatisk tilgang, for at kunne have en løsningsorienteret tilgang til specialet og har derudover valgt at være abduktive. Der er valgt case study som specialets strategi, for at gøre forfatterne i stand til at gå i dybden med problemstillingen for case virksomheden. Derudover gør forfatterne brug af både kvalitativt og kvantitativt data, for at indsamle så meget værdifuld data som muligt. Specialet har tidsmæssigt fundet sted over 4 måneder, og er derfor et "cross-sectional" studie.

For få en bred forståelse af problemstillingerne, er der udarbejdet et litteratur review. Litteratur reviewet har til formål at undersøge de potentielle industrielle formål som andemad har. For at få en forståelse af bioressourse udnyttelsen i dansk kontekst, er der fortaget interviews af nøglepersoner i de relevante industrier.

Resultatet fra litteratur reviewet viser at andemad er en proteinrig bioressourse, som kan bruges til fire forskellige formål. Det første formål er foder til den animalske produktion der er i Danmark. Det andet og tredje formål er produktion af bioetanol og biogas. Det fjerde formål er brugen af andemaden i bioraffineringsanlæg, til produktion af både proteinrigt dyrefoder, og et restprodukt der kan blive brugt til at producere biogas. Andemad bliver i litteraturen derudover beskrevet som en plante, der er god til at fjerne næringstoffer, såsom nitrogen og fosfor, fra spildevand.

Analysen viser at andemad, i dansk kontekst, kan blive benyttet direkte som foder til animalsk produktion. Det kræver dog varmebehandling af andemaden, for at fjerne uønskede bakterier og vira i biomassen. Den næste potentielle use case er brugen af andemad i biogasanlæg. Analysen viser at afsætning til biogasanlæg har to udfordringer. Afsætningsprisen er lav grundet stor konkurrence på markedet og andemad som proteinkilde bliver derudover ikke udnyttet. Denne del af analysen viser at bioraffineringsanlæg har det mest konkurrencedygtige afsætningspotentiale, samt bedste udnyttelse af andemad som bioressource i den danske proteinværdikæde.

Analysen af den optimale værdikæde for andemad har to hovedkomponenter. Høst af andemad på dambrug og transport mellem dambrug og bioraffineringsanlæg. Værdikæden har to potentielle indtægtskilder. Den første er indtægt for den økoservice vandrensning udgør på dambrug, som et produkt af høsten af andemad. Denne indtægt er bundet op på mængden af næringstofferne nitrogen og fosfor, som den fjernede andemad blandt andet består af. Den anden indtægtskilde er salg af andemad til et af tre danske bioraffineringsanlæg. Den økonomiske analyse viser at en afhentet container med 18 ton høstet andemad, vil generere en samlet profit på 512 kr. Denne beregning er baseret på det nystartede bioraffineringsanlæg, Biorefine Denmark.

Analysen beregner det samlede danske markedspotentiale fra et konservativt og liberalt perspektiv. I de to beregninger er der brugt en matematisk model, der medregner de varierende temperaturer gennem andemadens vækstsæson ud fra to forskellige tilvæksthastigheder. Resultaterne for det danske markedspotentiale, ved høst på dambrug, viser en årlig profit på mellem ca 341.000 kr. og 1,4 mio. kr.

Foruden de økonomiske resultater, påviser dette speciale også at høst af andemad på danske dambrug har en positive miljømæssig effekt. Derudover viser de socioøkonomiske beregninger at udnyttelse af andemad kan skabe vækst for dambrugsindustrien. For Danmark som produktionsland, kan andemad endvidere være en værdifuld kilde til nye proteinværdikæder i den danske bioøkonomi.

Abstract

This thesis seeks to analyse and present a solution for BioMend, that makes the harvest and sale of the protein rich duckweed species Lemna minor, grown on fish farm lagoons, feasible. To answer this, the researchers have conducted a throughout literature review, in order to first assess what use cases Lemna minor would be viable in. A market research was then conducted, in order to identify possible customers for the harvested duckweed. Lastly, a new value chain has been developed for the utilisation of the protein rich duckweed, together with a business case. The use case for the harvested Lemna minor is the nutrient reduction in the water of which the duckweed is growing, together with the biorefining of the duckweed into a protein concentrate and a fiber product. The nutrient reduction enables fish farmers to increase their overall production of fish, while the protein concentrate can be fed to animals, and the fibre product used to produce biogas. The customer identified for the biorefining is Biorefinery Denmark, located in Jutland, which specialize in the biorefining of green biomass. The developed value chain mourned out in the harvest, transport and sale of Lemna minor grown on fish farm lagoons. Lastly did the solution present a positive business case, with a calculated break-even of approximately 13.000 kg harvested duckweed, in order for the solution of harvest, transport and sale of Lemna minor, to be feasible. Transport of up to 18.000 kg of harvested duckweed is possible, showcasing that a full harvest will result in a profit of 512 DKK for BioMend.

Preface

The thesis, *Assessment of the utilisation of duckweed: A development of a new protein value chain*, has been conducted by the student Andreas Bech Lundsgaard and Kristian Klougart Hansen from Aalborg University CPH. This report fulfills the requirement of the Masters thesis in Operations and Management Engineering and represents 30 ECTS points. The Thesis was written during the spring semester 2021, from February to June. The Thesis was written under supervision of Liliya Altshuler Oxtorp, PhD at the department of Materials and Production.

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1 Introduction

The world population growth combined with the increasing demand for high quantities of food, energy and natural resources, has a large impact on the world. The negative results of this, are seen in the excessive greenhouse gas emission and nutrient emission to the water. This has in resent years increased the search for alternative sources of food, that can be used as energy feedstocks. Furthermore, has alternative protein sources to replace soybean been of interest, to reduce the national import. This has triggered an increased interest for the use of alternative biomasses. Lastly, has fish farms since the 1980's struggled to meet the national goals set for nutrient emission by the government. This has lead to a reduction in the total number of active fish farms. The national goals for nutrient emission is based on international agreements in the European Union. There is an increased pressure to decrease nutrient emission while increasing the national bio-economy.

The Danish start-up, BioMend, has the declared goal to reduce the nutrient emission to both freshwater streams and the ocean through aquatic biomass production. BioMend want to make it economically feasible to perform bioremediation, that is the decreased emission of nutrients to the environment. A practice that today is costly for the society.

As a large amount of the feedstocks for energy and protein are soil grown crops, a possible candidate to replace them, would be a crop that is not grown on soil.

BioMend seeks to be a start-up with a sustainable view by utilising biomass growing in Denmark, and thereby the strengthen the Danish bio-economy. Duckweed has been identified by BioMend to be a candidate, that can be utilised as an alternative method for bioremediation and biomass production.

This thesis aims to support BioMend in the development of a new value chain for duckweed grown in the lagoon areas of fish farms in Denmark, and also present a economically feasible solution for the utilisation of the grown duckweed.

The thesis utilises existing literature that presents the industrial possibilities for duckweed and alternative bioresources. Furthermore, is the potential use of duckweed analysed in the context a Danish market.

2 Pre-analysis

The pre-analysis of this theses will cover the overall relevance of utilisation of biomass production on an international and national level. Furthermore will the case company of the project, BioMend, be presented and described. Lastly is the biological properties of Duckweed assessed as support for the later investigation of potential use cases and further financial evaluation.

2.1 Call for bio-resources

At an international and national level, the call for lower nutrient emission into water streams and the oceans has created a need for better utilisation of natural bio-resources in countries around the world. One of the first steps towards intensified community policies and legislation on water resources in the European Union was in 1988. This was the "Developing community water policy conference" (European Commission, 1988) where nine areas of improvement of drinking and surface water were agreed upon.

The 1988 Commission on water policy lead to the directive 2000/60/EC, published in 2000 (latest update in 2014) by the European Union. It is titled: "establishing a framework for Community action in the field of water policy" (European Union, 2000). The directive contains clear goals and specific guidelines for each member state to follow in order to achieve the goals. The goals crated a specific focus on preservation of drinking water resources and surface water. Furthermore, the directive defines unwanted chemical substances and defines tiered levels for water quality status in regards to emitted nutrients like nitrogen and phosphorus.

In 2012 the European commission adopted the strategy: "Innovating for Sustainable Growth: A Bio-economy for Europe" (European Commission, 2012). The bio-economy in Europe is estimated to employ 22 million people and and have an annual turnover of two trillion Euros. The strategy is pushed by the urge to tackle the societal challenges lying ahead. This is described in European Commission (2012) as the following: Firstly the global increase in food demand of 70% by year 2050 by "developing the knowledge-base for sustainable increase in primary production" (European Commission, 2012). Furthermore, capital investment and funding will be provided for private companies that can lead the way within these areas. The second challenge is sustainable management of natural resources like agriculture, forestry, fisheries and aquaculture. The current exploitation have put natural resources under severe pressure and is linked to depletion or loss of ecosystem services. The third challenge is the current dependency on non-renewable resources. This dependency will need to shift towards bio-based products as a contributor of both renewable energy and biofuel. The fourth challenge is to mitigate and adapt to climate change. The objective is to move to a low-carbon economy. This will happen partly through substitution of carbon, energy and water intensive production processes in favor for resource efficient and environmentally friendly production (European Commission, 2012).

2.2 National incentives

As a member state in the European Union, Denmark is committed to the common goal of increasing the utilization of natural resources. The Danish strategy for bio-economy is partly influenced by the strategy of the European Commission, mentioned in section 2.1. but other member countries like Sweden, Germany, the Netherlands and France also has an influence. In the COWI report (Ministry of Environment & Food, 2018), initiatives and strategies from the above mentioned European Union member states are assessed. This is to understand which technologies, marked developments, partnerships and capital investments that has proven effective in the development and implementation of new protein value chain. The report conclude four main areas for development (Ministry of Environment & Food, 2018):

1. Denmark should increase governmental capital investment in private initiatives and research. Furthermore should Denmark continue to follow the initiatives of neighbor countries to understand the long term impact of initiatives.

2. The current legislative basis in Denmark does not adequately encourage development of the Danish bio-economy. This creates barriers, that prevent further learning across sectors. Furthermore, public tender programs should help increase investment in Danish bio-economy.

3. The concept of "bio-based" need to be better integrated in the industry of bio-technologies, agriculture, the food sector and in the bioenergy sector. This will make it easier to fit financing and up-scaling mechanisms into the future strategy for bio-economy.

4. Finally the report shows that private investors are already focused on the bio-economical growth potential. But supplementary funding from the government would accelerate growth and security within private investment in the bio-economy.

2.2.1 Governmental action plan

The Danish National financial act of 2013 included an economical boost of bio-economical remedies (Ministry of Finance, 2013). This boost gave birth to the inter-ministerial secretariat of the National Bio-economy Panel in 2013. The main task of this panel is to provide evidence based suggestions for improved bio-economy and expanded business community. The insight is delivered to the three Ministries of "Environment, Food, agri- and aquaculture", "Climate, energy and supply" and "Education and research". In 2016 the National Bio-economy Panel was reorganised to provide more specific results and suggestions that were easier to implement into the society. The tools used by the Ministries are capital subsidies and legislative changes.

The Strategy for increased Danish bio-economy base its foundation in the Europe Commission's "Strategy for Bio-economy" described in section 2.1. The strategy will be realized through the following three initiatives:

1. Capital investment in research and development

2. Development of the marked of bio-based production

3. Increased stakeholder involvement

Biomass as a resource is divided into eight topics of research. This is done to intensify the research of each specific area of biomass. These areas will define the topics that this study will contribute to (see table 1).

Biomass areas	Biomass	New value chain
Blue Biomass	Discard-Fish	Human consumption
Blue Biomass	Macroalgae	Fodder and Health products
Green Biomass	Grass, clover and other plant parts	Crude protein for fodder
Yellow Biomass	Straw	Biofuels
Brown Biomass	Energy wood as a chip	Bio-gas
Red Biomass	Residual products from meat production	Fodder and protein powder
White Biomass	Whey protein	Crude protein for human consumption
Residual Products	Household waste	Bio-gas

Table 1: Biomass areas of development (NaturErhvervstyrelsen, 2015)

In order for the marked of bio-based products to expand, a number of potential new value chains has been described in figure 1. Within each Biomass-area, necessary requirements to the Biomass as well as process diagrams are analysed. This will guide the involved stakeholders to operate within the different biomass value chains. Lastly, the main barriers for integration of the new value chains are analysed to prepare changes in the legislation, in favour of involved stakeholders.

2.2.2 Capital investments in bio-economy

The governmental capital budget contributes to two main areas to increase the bio-economy in Denmark (The Danish parliament, 2020).

1. Ambitious and lasting green research initiatives
   - Innovation Fund Denmark and Independent Research Fund
   - Development and Demo program (MUDP and GUDP)
   - Agriculture
   - Design and Architecture
   - Climate and Geopolitics
2. Technology and innovation to maintain production and jobs in Denmark
   - Innovation Fund Denmark
   - Match financing scheme (Vækstfonden)

The first area of funding is mainly for research and initiatives that can be implemented in the Danish society. The funding is not only restricted to public universities but through the Development and Demo programs, private companies and startups are able to receive the necessary funding to kick start innovative ideas. The goal is to create new job opportunities that can provide growth within the Danish bio-economy. Every year the Development and Demo Programs focus on a new main area of development that is supported. The main focus of 2021 is to fund projects that support development of new sources of protein either for animal or human consumption.

The second area of economic support, is given to public institutions and private companies in order for Denmark to maintain already existing jobs in companies that contribute to the bio-economy.

Within both areas of governmental funding, the the environment is in focus. The perspective of the latest economical plan form the government (The Danish parliament, 2020) has four main objectives (The Innovation fund, 2021).

1. Capture and storage or use of CO_2
2. Green fuel for transport and industry (Power-to-X)
3. Climate and eco-friendly agriculture and food production
4. Circular economy with focus on plastic waste and textile

In year 2021, the government has allocated an additional 750M.DKK (The Danish parliament, 2020) to boost the economy, in the aftermath of the CoVid-19 epidemic.

2.2.3 Knowledge base within bio-economy

A number of sectors contribute either indirectly, partially or as a core contributor to the bio-economy of a country. Beluhova-Uzunova et al. (2019) defines these sectors shown in table 2.

Contributors to bio-economy	Included sectors
Core bio-economy	Agriculture, forestry, fisheries and aquaculture
Partial bio-economy	Chemical and plastic industry, construction, pharmaceutical and textile industry, waste management and biotechnology
Indirect sectors	Technologies, machinery, retail trade, water supply, services

Table 2: Bio-economy sectors (Beluhova-Uzunova et al., 2019)

In Denmark the core bio-economy is provided by the sectors that produce the eight biomass areas shown in table 1. To increase the utilisation of the biomass areas, the Danish government has allocated additional funding to public and private organizations that make research and development. The Danish universities has in recent years allocated a larger amount of their resources to environmental benefiting research. This happened in part because of the Paris Agreement in 2015 (United Nations, 2015; Aarhus University, 2020; Technical University Denmark, 2020). The Danish universities play a key role in Denmark's strategy to reach a 70% CO_2 reduction before 2030. In 2017, 22,4% of Denmark's emitted greenhouse gasses (CO_2 equivalent) were emitted from the industry of agriculture (Ministry of Food, Agriculture and fishery, 2019). Due to the high emission, linked to agriculture, research has evolved around this industry. From the perspective of bio-economy, universities and private organisations have in 2020 received funding for almost 2.500 projects from the European research and innovation program Horizon 2020. The total funding from the European Union accumulates to about €1.5 billion (Ministries of education & research, 2020).

The Danish research strategy is supported by funding from both the European Union and the Danish government. The strategy to increase green research and bio-economy includes the following seven research areas (Ministries of education and research, 2020):

1. Energy production
2. Energy optimization
3. Agriculture and food production
4. Transport
5. Environment and circular economy
6. Nature and Bio-diversity
7. Sustainable behavior and societal consequences

2.3 BioMend startup

The startup is owned by three newly graduates from Roskilde University, with a Master degree in Environmental Planning and one person currently studying Operations and Management Engineering at Aalborg University (co-author Kristian Klougart Hansen). The vision of BioMend to tackle three main issues for the environment and society:

1. Nutrient emission to fresh water streams and the ocean
2. Extensive usage of virgin nutrients in Danish agriculture
3. Lacking conceptualisation of circular economy

The concept of BioMend has been in steady development since 2018. Here it begun as the idea to industrialise the concept of Aquaponics[1]. Through analysis of the industry of Aquaculture in Denmark, it was discovered that the industry has a number of issues that needed to be addressed. The biggest problem for the industry is the nutrient emission to the environment. This issue puts a legislative limit on the total fish production in the industry. By understanding the nature's nutrient cycle and the human nutrient emission, the idea to utilise plant growth as water cleansing method was hatched.

The strategy of BioMend is to decrease the emission of nutrients to the environment from the Agri- and Aquaculture industry through biomass production. The goal is to develop a water

[1] An integrated culture of plants and aquatic animals, most often fish, in a system where the water is recycled. The form of production is a combination of aquaculture and a cultivation principle for plants, called hydroponics, which is based on liquid nutrient allocation and growth without soil (Aarhus University - PURE, 2009)

cleansing solution that is economical sustainable. The first stage of the idea will be applied at a fish farm. BioMend will need economical support in order to develop this solution, which will be elaborated in section 6.4.6

BioMend has at this point been running an experiment at Roskilde University as part of a Master's Thesis by three of the co-founders (Nørgaard et al., 2021). The experiment investigated the biomass production of duckweed, in a water medium simulating the nutrient levels in the lagoon at fish farms. The results of this experiment showed an average harvest of duckweed between $180g/m^2/day$ and $302g/m^2/day$ (Nørgaard et al., 2021). In relation to the definition of the Innovation Found Denmark is BioMend now at the "Technology Readiness Level" TRL3 (The innovation Found Denmark, 2020). TRL3 is the experimental proof of concept where the first laboratory scale prototype has been realised. The above mentioned experiment showed promising results as a proof of concept, both within duckweed's ability to remove excess nutrients from wastewater and the total biomass production. Within year 2021, the goal is to apply for funding for technology validation in relevant environment - TRL5. The location for this prototype will be Mølgaard fish farm, that is owned by the Chairman for Danish Freshwater Aquaculture, Peter Holm. The specific design of this prototype will be based on both this Thesis and further development during July and August 2021.

2.4 Biomass for water cleansing

BioMend has investigated a number of potential types of plants as biomass for the water cleansing. The criteria for finding a suitable biomass is:

1. High growth rates
2. Adaptability for the nutrient levels at fish farms
3. Resilient to the temperatures at fish farms
4. Minimum labour requirements
5. Not a invasive type of plant to the environment

A type of biomass that has high growth rates will serve two purposes. First being a larger nutrient uptake from the grow medium than a slow growing plant. This is important to ensure sufficient water cleansing ability at the fish farm, thus creating value for the fish farmer. The second reason for the high growth rate, as a requirement, is that larger quantities of biomass will be easier to sell at an industrial scale.

The plants ability to sustain a high growth rate at various nutrient levels is important. At the fish farm, the feeding rate of the fish variate throughout the year. During spring and fall the feeding rates will often be the highest. This will result in the higher emission of nutrients in these periods.

The temperatures at a fish farm is determined by the weather, as the water used in the fish farm, comes directly from fresh water streams and must be send back into the same stream without significant changes to the temperature. The temperature in freshwater streams variate during the year, depending on the air temperature. Most plants will grow in temperatures above +5 degrees Celsius. In Denmark, the water temperature typically lies above 5 degrees 7-8 months a year [2]. The plant chosen for the system must be able to endure the environmental conditions.

The requirements to the labour intensive maintenance is an important factor when finding the most suitable plant for the system. An example is Annual plants[3], that can not sustain a large plant culture year on year, and will require more labour and cost for sowing the plant

[2] The average water temperature in Denmark(Climate-Data, 2021)
[3] Plants that germinate, produce seeds, flower and die in one year

every year. Further more is it preferable to find a plant that require a minimum maintenance during the growth season.

The last requirement for the plant is the environmental fit. This means that the plant can not be an invasive species in the local biosphere. The water cleansing system will to a high degree be cut of from the nearby environment. At the same time will the system share water with the surrounding wild nature, thus is invasive plants not allowed.

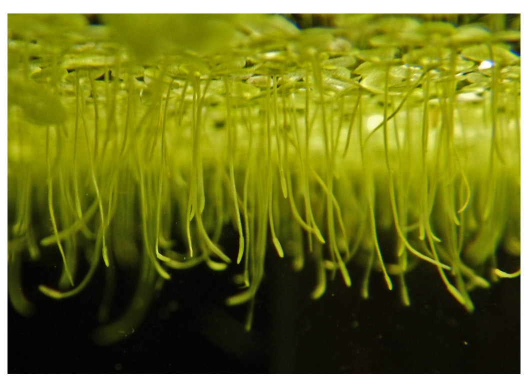
2.4.1 Potential for duckweed as biomass

Duckweed is chosen for the system. The idea for using this type of plant stems from a visit at a fish farm. Here it was discovered that duckweed grows naturally at the lagoon area in large quantities. The lagoon serves to recirculate the water, used for the fish production, back into the water stream. The lagoon does thus contain a large amount of nutrients, from the waste that the fish produce. These lagoons are placed right before the water is lead back into the water stream (see appendix F). The fish farmers are required to implement a lagoon area in the nutrient management system, to reduce nutrient emission to the environment. Further investigation show that duckweed grow naturally at all fish farms as well as in fresh water streams, small lakes, water holes and on the lagoon areas of water treatment facilities for human waste. This means that the plant is not invasive for the biological environment.

The plant duckweed is in literature referred to as an umbrella description called the Lemna family (Landolt and Kandeler, 1987). It is a large family with different sub species. In Denmark, three species of the duckweed family can be found. According to Frederiksen et al. (2006) Lemna minor is the most common species in Denmark, with small differences in structural properties to the other species. The two other species are called Lemna gibba and Lemna trisulca.

Lemna minor is a freshwater plant found in most slow moving bodies of water. As seen in the two pictures in figure 1 page 7, the plant has just few leafs and a single root in its most basic form. Lemna minor grow by producing a "daughter" plant that is attached to the "mother" plant in the beginning. When the new plant has grown to a sufficient size, it will split from the mother plant. The mother plant will continue to produce daughter plants throughout it's life span of 40-60 days (Landolt and Kandeler, 1987). The same applies to all daughter plants. The growth can be described as exponential. The growth rate of Lemna minor depends on the the environment where it grows, but have the potential to double in count of plants every 20^{th} to 24^{th} hour (Landolt and Kandeler, 1987). Ge et al. (2012) argues that Lemna minor have a growth rate between 3,5 - 14,1$g/m^2/day$ in dry weight. The dry weight of the plant varies depending on the growth conditions. In the experiment conducted by BioMend at Roskilde University, was the dry matter content of Lemna minor measured to be 5%.

(a) Top view



(b) Side view

Figure 1: Lemna minor plant (Wikipedia, 2021)

Lemna minor grows through the process of photosynthesis. Beside the uptake of CO_2, the plant will take up a number of nutrients from the growth media through the root. Just like other plants is the maximum growth limited by Liebig's Law of the Minimum[4]. That makes the right nutrient composition in the growth medium important. In table 3 can the nutrient composition of Lemna minor be seen[5].

Nutrient content (% of dry matter)	K	Na	Ca	Mg	Mn	Zn	Fe	P	N
Lemna minor	1,53	0,02	0,18	1,92	0,03	0,05	0,06	0,83	8,74

Table 3: The nutrient content of Lemna minor in dry matter(Landolt and Kandeler, 1987)

Duckweed is a versatile plant that can grow under a wide variety of nutrient compositions, both at low and high concentrations. According to Cheng and Stomp (2009) is Lemna minor, compared to other freshwater plants, good at sufficient nutrient uptake in conditions with both high and low nutrient content. Lemna minor can for this reason be used for nutrient removal from wastewater. For this purpose it is required that the plants are removed / harvested before they die. When the plant dies, it will sink to the bottom of the water and start to decompose. In this process, the nutrients contained in the plant, are released back into the water. By performing continuous harvest can the duckweed production be seen as a water cleansing method.

Beside the ability to cleanse water, duckweed as a biomass contain structural properties that can prove desirable for a number of use cases. As seen in table 4, duckweed is able to have a very high concentration of both protein and carbohydrate.

Mineral content of Lemnaceae (% of DM)	Minimum reported content	Maximum reported content
Proteins	6,8	45,0
Lipids	1,8	9,2
Crude fibres	5,7	16,2
Carbohydrate	14,1	43,6
Ash	12,0	27,6

Table 4: Content of Lemnaceae (Landolt and Kandeler, 1987)

Because duckweed can pickup a lot of minerals found in the water, the plant will also be able to pick up heavy metals. These metals are not desirable to have in products that are used for either human or animal consumption. For that reason, it is important to ensure that the growth medium does not contain high levels of heavy metals. The duckweed of interest to BioMend, is cultivated on lagoons that is used for fish production for human consumption. Therefore, it can be assumed that the water does not contain any significant amount of heavy metals.

[4]Plant's need for all types of nutrients in order for optimal growth. By lacking access to one type of nutrients, the growth potential will be limited (van der Valk, 2011)

[5]The nutrients content at highest level in the plant

3 Problem statement

Derived from the pre-analysis, the following problem statement is defined:

How can BioMend develop a feasible solution for the utilisation of naturally cultivated duckweed in Denmark?

The following research questions has been composed, in order to adequately answer the problem statement.

1. What are the potential industrial uses of duckweed?
2. Who are the potential Danish customers for duckweed at an industrial scale?
3. What is the most feasible value chain for the utilisation of duckweed?
4. What is the business case for the proposed value chain?

Question one aims to gather knowledge about the industrial possibilities that duckweed can be used for.

Question two seeks to identify potential Danish customers, that deals with the industries found in question one.

Question three seeks to identify a value chain that is feasible for BioMend to pursue, with the use cases and customers found from question one and two in mind.

Question four seeks to evaluate the business case that the value chain presented to BioMend can generate, and how the solution affects BioMend as a company.

4 Literature review

The first part of this section will revolve around the framework for the literature search. Next, is the found literature within each research area evaluated. This literature review is a collection and review of relevant articles, papers and other academic literature. The purpose of gathering the literature is to gain enough theoretical knowledge to be able to answer the problem statement, as well as the research questions, formulated in section 3.

4.1 Literature search

The search for literature is based upon the model presented by Bryman and Bell (2015) which is shown in figure 2 below.

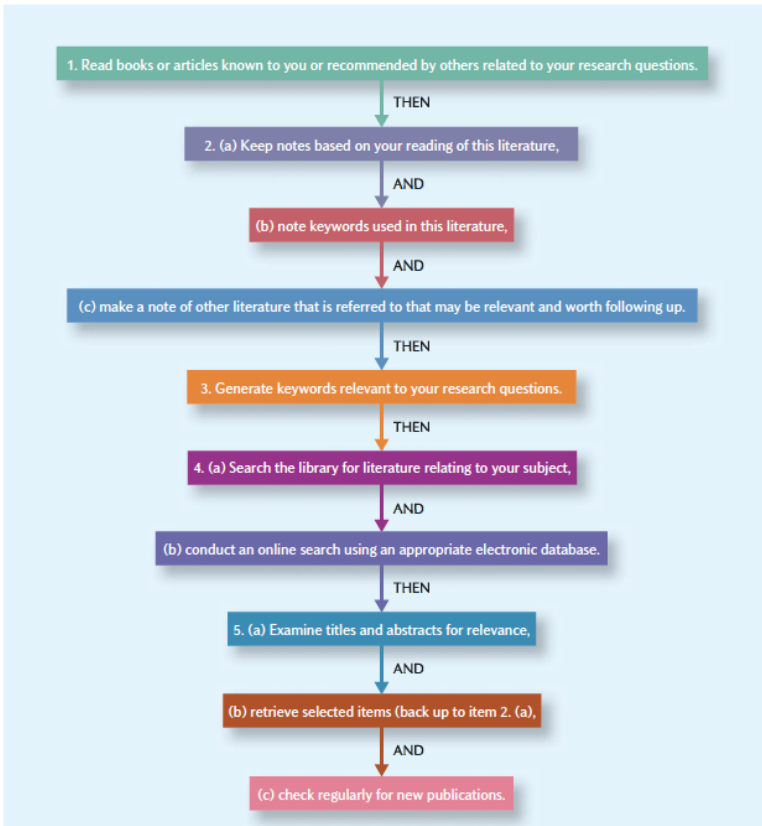


Figure 2: Strategy for literature search (Bryman and Bell, 2015)

This is a step by step strategy to find relevant literature and encouraging preliminary use of already known material in order to generate keywords for the later search steps. The pre-analysis in section 2 and the research questions formulated in section 3 are also used to generate the keywords for the search. Furthermore does the framework encourage the use of an electronic database to conduct online search for literature, and proposes the examination of titles and abstracts for relevance as a means to quickly find relevant literature. This approach to find relevant literature will be used as an evaluation model, which is done in section 4.1.3.

4.1.1 Search Engine

In order to find the relevant literature, the search engine ProQuest.com will be used as the online search library. ProQuest is an online search database containing millions of different published works from around the world. Necessary search functions and filter can be added before or during the search, thus making it an ideal choice for literature search.

4.1.2 Search Words

As seen in step 3 in figure 2, the model calls for the generation of keywords that has relevance for the research questions. The research questions formulated for this thesis will be used to generate keywords of relevance. Other means of generation of key-words like brainstorm and the pre-analysis will also be used. The main search word is duckweed, and in order to specify the search, strings was added to help narrow down the results.

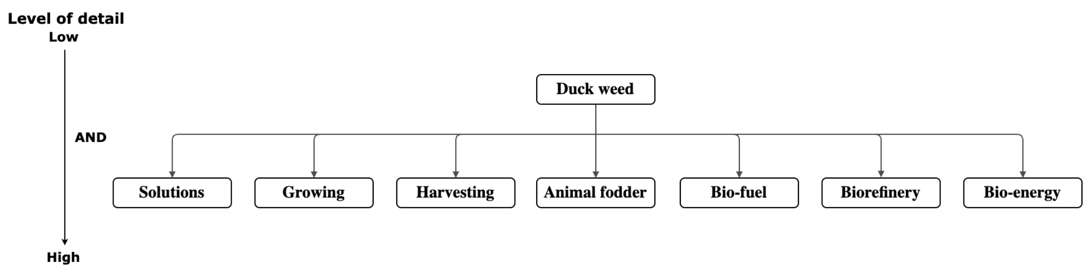


Figure 3: Key words for literature search

4.1.3 Outcome of the search

When searching for literature, there is the possibility to limit the results to be within a certain publication year. As relevant literature about duckweed has been found (Leng, Stambolie and Bell, 1995), which is from 1995, the choice to not put any limit on the publication year has been made. The outcome of the literature search can be seen in table 5 below.

Search words	Search strings	Results	Relevant
Duckweed	Duckweed	14.472	0
Bioenergy	Duckweed AND Bioenergy	724	0
Biorefinery	Duckweed AND Biorefinery	230	3
Biofuel	Duckweed AND Biofuel	688	1
Animal fodder	Duckweed AND Animal fodder	576	1
Harvesting	Duckweed AND Harvesting	2.295	0
Growing	Duckweed AND Growing	5.967	1
Solutions	Duckweed AND Solutions	6.597	0

Table 5: Search results of the literature search

As seen on table 5, the search accumulates to 31.549 results, with the two biggest search strings being "Duckweed" and "Duckweed AND Solutions".

The evaluation model, described earlier in figure 2, will be applied to the literature search that is done using ProQuest, which will help sorting through the large amount of literature that the results presented. The evaluation model consists of four steps, the first one being that the evaluation of results were limited to the first five pages. Each page contains 10 articles or papers, which accumulates to 50 papers for each string. Secondly, the headlines of each result were read in order to establish whether or not the article or paper seemed relevant. Thirdly, if the headline was deemed relevant, the abstract would be read in order to gain a brief understanding of the literature. If the abstract seemed to fit the purpose, the entirety of the paper would be read in full.

From the rightmost column in figure 5, it can be seen that from the entire search, a total of six relevant articles or papers was found, containing relevant secondary qualitative as well as quantitative data about duckweed. These papers will be read in detail in order to gain as much knowledge as possible. Furthermore was relevant references in the found literature reviewed for further understanding of context, background knowledge and new information.

4.2 Search for business case framework

As stated in section 2.1, there is a call for better utilization of natural bio-resources in countries around the world (Cheng and Stomp, 2009; Zhang et al., 2012; Cui and Cheng, 2014). Furthermore, Cheng and Stomp (2009) argues that the energy/climate change challenge, and the role of plant biomass as a source of carbon compounds to supplant petroleum as well as a chemical feedstock, has altered the debate regarding the idea of developing duckweed as a crop. Sońta et al. (2019) also claims that a search for alternative protein sources to replace soybeans in animal diets, has triggered a renewed interest in the use of other bio masses. In order for plant biomass to play a significant role as an energy feedstock and animal fodder solution, there would have to be a massive increase in plant production (Cheng and Stomp, 2009).

4.3 Use case for duckweed

To avoid the possibility of a collision between the demand for energy and animal fodder, with the increasing demand for crop commodities, which could be grains and legumes, new crops and agricultural systems may be needed. The obvious choice would be to look for plants that can grow without the need of soil, but instead in nutrient-rich waters. Plants that grow in nutrient rich waters, such as aquatic plants, are contrast to soil-based crops able to directly absorb nutrients from the water (Cheng and Stomp, 2009). A crop grown in nutrient-rich water, such as wastewaters, would remove the need for the use of land. Furthermore, the wastewater ponds could be made on land that is unsuitable for soil-grown crops, resulting in the wastewater ponds not taking up any useful land. This way, the aquatic crop would be able to add to the global plant biomass supply, without competing for the limited supply of arable[6] crop land (Cheng and Stomp, 2009).

The ideal plant would be able to tolerate the varying levels of nutrients found in wastewater, and the varying forms of nitrogen, that can be found. Furthermore, the ideal plant should be able to tolerate and utilize high concentrations of ammonia, which is also found in some wastewaters (Cheng and Stomp, 2009). Ideally, the grown plant should have a fast growth rate, resulting in multiple crops each year, and in order to maximize yield, the the plant should contain protein, carbohydrates, lipids and specific chemicals, in the entire plant, and not just as a seed, root or stem. Cheng and Stomp (2009) argues that soil-based crops loses a considerable amount of biomass through crop residues that are left in the field. A water grown plant that gets fully harvested, is better utilized. In order to minimize handling and transportation of the biomass after it has been harvested, the biomass should be able to dry relatively fast, with minimal energy inputs. This could mean that an on site drying solution could be needed, in order to dry the biomass before being transported, as to not transport a lot of unusable water.

4.3.1 Characteristics of duckweed

Duckweed, also called Lemnaceae, is a small, free-floating aquatic plant that forms mats on or beneath the water surface, and grows best in nutrient-rich waters (Sońta et al., 2019) such as wastewater, where nitrogen and phosphorus is present, as described in section 2.4.1. The reason for this being that one attribute to duckweed growth is the absorption of the different nutrients found in wastewaters, such as nitrogen and phosphorus (Cui and Cheng, 2014). Thus duckweed

[6]Arable land is any land capable of being used to grow crops

can most likely be found growing on wastewaters containing these two nutrients. This makes duckweed a plant that is likely to be associated with wastewater treatment, with the purpose of nutrient removal. Lemnacae contain between 3 - 14% dry matter (Landolt and Kandeler, 1987), with the rest being water. A total of 37 species exists, which is categorized into four genera, namely *Spirodela, Lemna, Wolffia* and *Wolfiella*. All members of the duckweed is seen grown across the globe with the sub species Lemna minor being very abundant in Denmark, as written in section 2.4.1. Duckweed inhabit freshwater ponds, pools and wastewaters, preferring those that are shallow and with little to none flowing water Cheng and Stomp (2009). Because duckweed is susceptible to being moved by wind and water currents in the water basins and ponds in which it grows, wind speeds of of the ponds should not exceed 0,3 m/s (Sońta et al., 2019). Some of the duckweed species inhabit characteristics that matches the attributes of the ideal plant, which makes them a good candidate for wastewater based agriculture.

Some species can achieve near exponential growth rates, with doubling times varying by species and environmental conditions, resulting in doubling times as short as 20 to 24 hours, while other species can achieve it in two to three days (Cheng and Stomp, 2009). The growth rate, composition, and amount of biomass harvested from duckweed is dependant on several factors. These include the nutrient concentration (nitrogen and phosphorus) in the growth medium, the temperature and pH, sun exposure, day length, and lastly wind speed. According to Sońta et al. (2019), the optimum growth conditions regarding temperature is between 20 and 28°C. In order to optimize the production, continuous harvest of the duckweed biomass is necessary, with intervals varying depending on the growth rate of the duckweed, and the size of the pond. The continuous harvest will ensure that there is always space in the pond for the duckweed to grow on. Goopy and Murray (2003) argues that once the surface of a body of water is completely covered with duckweed, the plant has limited further opportunities to grow.

Duckweed production can provide four to five times as much protein per hectare compared to soybean (Sońta et al., 2019). Furthermore, duckweed is not genetically modified, and requires no farmland nor chemical fertilizers (Sońta et al., 2019). Sońta et al. (2019); Cheng and Stomp (2009) argues that the protein content in the dry matter of varying duckweed species range from respectively 7-45% (most often 20-45%) and from 15 to 45%, while Landolt and Kandeler (1987) argues that the protein content of varying duckweed species range from 6,8-45%. These values places the protein content of duckweed close to soybeans, which has a protein content ranging from 33-49% (Cheng and Stomp, 2009). With these amounts of protein, Sońta et al. (2019); Cheng and Stomp (2009); Goopy and Murray (2003) have recognized duckweed as a viable source of protein for farm animals. Furthermore, Landolt and Kandeler (1987); Sońta et al. (2019) claims that the amount of carbohydrates, also known as starch and sugars, in varying duckweed species, ranges from 14-44%. To compare, the starch content of corn ranges from 65-75% (Cheng and Stomp, 2009). With it's relative high concentration of carbohydrates, Cui and Cheng (2014); Cheng and Stomp (2009) argues that duckweed is a good candidates used to produce bioethanol and biogas, which are promising alternative energy sources compared to crude oil, natural gas and fossil fuels.

Organic components	Percentage
Proteins	6,8 - 45,0
Lipids	1,8 - 9,2
Crude fibres	5,7 - 16,2
Carbohydrates	14,1 - 43,6
Ash	12,0 - 27,6

Table 6: Variations of organic components in duckweed in % of the dry weight (Landolt and Kandeler, 1987)

4.3.2 Using duckweed as animal fodder

Fresh and dried duckweed is willingly consumed by animals, including poultry (hens, chickens and ducks) as well as cows, sheep, goats, swine and fish (Sońta et al., 2019). It has been demonstrated that the use of duckweed in moderate amounts or use as a partial replacement of other protein rich materials, including soybeans, has a beneficial effect. The beneficial effect includes productivity, fattening and slaughter performance of livestock and poultry, as well on the quality of their meat and eggs (Sońta et al., 2019). Some concerns have risen over the ability to accumulate heavy metals such as cadmium, chromium and lead. Heavy metals can threaten the rate at which it grows, as well as the health of animals and humans, should they consume it. In order to prevent this, the levels of heavy metals in the grown duckweed should be monitored during the growth and production phase of animal feed stuffs. The amount of metals absorbed is dependant on the chemical form, as well as the living conditions of duckweed (floating, suspended on the water surface, rooted or not (Sońta et al., 2019)). To avoid the heavy metals, growth of duckweed on natural water resources, household sewage or life stock waste can drastically limit the amount of metals that the duckweed can absorb, as these water sources contains low concentrations of the above heavy metals (Sońta et al., 2019). Studies concerning the amount of various elements in duckweed, including Cd, N, Cr, Zn, Sr, Fe, Mn, Cu, Pb, Al and Au, concluded that with low content being present, duckweed may provide a good source of feed for farm animals (Sońta et al., 2019).

4.3.2.1 Poultry - Broiler chickens

Sońta et al. (2019) describes a number of experiments regarding duckweed mixed in the diet of Broiler chickens. One experiment, tested a diet containing 100, 150, 200, 250 or 300 grams duckweed pr. kg fodder. The experiment showed positive production results with duckweed levels at or below 150g/kg. Adding more than 150g resulted in poorer production results, namely decreased feed intake and decreased body weigh gain. The broiler chickens fed a diet with 0 duckweed reached higher body weight gains and feed intake compared to the broiler chickens fed the diets containing duckweed.

Another experiment, conducted by Haustein et al, 1994, in Sońta et al. (2019) investigated chicken's diet mix of respectively 10, 15 or 25% duckweed. The results showed that the diet with 15% duckweed gave similar body weigh gains of that compared to a diet containing 0% duckweed. At 25% duckweed, body weight decreased and feed intake from the chickens were reduced.

An investigation regarding whether or not duckweed could be used as an additional protein source for broiler chickens at commercial farms, used a control diet (0% duckweed) and an experimental diet (5% duckweed). The results showed a positive final outcome indicated by higher body weight gains reached by the experimental diet compared to the control diet (Sońta et al., 2019).

A third experiment replaced sesame oil cake with respectively 0, 3, 6 or 9% dried duckweed. The results showed that the addition of 3 or 6% duckweed to the diets improved body weight, feed conversion and profitability of the chickens, compared to 0% and 9% duckweed. Poorer results were achieved when replacing 9% of the sesame oil cake with duckweed (Sońta et al., 2019).

Lastly, an experiment administered diets containing respectively 0, 4, 8 and 12% dried duckweed to chickens until 42 days of age. The results showed that the chickens given the diet containing 0% duckweed achieved the best production performance. Increase of duckweed in the diet resulted in negative effects. That being slower body growth of 1,39 kg vs. 1,02 - 1,28 kg, lower feed intake of 2,50 kg/broiler vs. 2,31 - 2,46 kg/broiler, lower feed conversion ratio [7] of 1,69 kg vs. 2,11-2,51 kg and lastly a lower consumption of protein and energy (Sońta et al., 2019).

With these experiments in mind, Sońta et al. (2019) argues that the inclusion of duckweed

[7] Feed conversion ratio is the amount of crops/feed that is required for the production of a unit of meat or the desired output (Animal Care Practice, 2020)

in the diet of broiler chickens is not recommended. However, seeing that some experiments showed positive results, albeit only with the use of low amounts of duckweed, there could be reason for further research into the use of smalls amounts of duckweed in broiler feeds.

4.3.2.2 Poultry - Laying hens

A 16-week experiment was conducted on egg laying hens, in which the proportions of rice polish and fish meal were decreased, with increasing proportions of dried duckweed. The control diet had 0 g/kg duckweed, and the experimental diets had 50, 70, 110, 130 and 150 g/kg duckweed. According to Sońta et al. (2019), no differences were observed between any of the groups regarding traits such as body weight, egg weight, and livability. However, With the increasing proportion of duckweed in the diet from 0 to 150 g/kg, feed intake decreased from 769 g to 713 g. Egg production decreased from 42,9 mass/g/egg/day to 33,5 mass/g/egg/day and feed conversion ratio decreased from 2,54 kg to 3,04 kg. With this in mind, Sońta et al. (2019) argues that duckweed is a good source of protein for egg laying hens, without any negative effects on production performance with up to 130 g/kg added duckweed, and on egg quality characteristics with up to 150 g/kg added duckweed.

In another experiment, soybean meals was replaced with duckweed in order to see its effects on production results and egg quality of egg laying hens. The control group was fed the normal diet, while the experimental group was fed 12,5% substitution of soybean meal with duckweed. The use of duckweed did not change the egg production of the experimental group, and no difference were observed in the nutrient composition of the eggs (Sońta et al., 2019).

In conclusion, the use of dried duckweed in the diets fed to egg laying hens proved beneficial, and the authors of the experiments suggested that duckweed could be used as a new supplement, as a cheaper alternative to inorganic dietary additives (Sońta et al., 2019).

4.3.2.3 Poultry - Ducks

According to Sońta et al. (2019), researchers used fresh water spinach and fresh duckweed together with rice diets to feed ducks. The treatment was separated into three groups, with the first one receiving a 80:20 mix of water spinach and broken rice. The second received a 80:20 mix of duckweed and broken rice, and the third group receiving a 35:45:20 mix of water spinach, duckweed and broken rice. Of the three groups, the daily weight gain was lowest in the first group (6,2g) and highest in the second (22,4g). Feed conversion ratio was poorest in the first and third group (respectively 9,1g DM/g body weight gain and 4,3 g DM/g body weight gain, with DM being dry matter/fodder) compared to the second group, which had a feed conversion ratio of 3,8 g DM/g body weigh gain. So the second group gained 1 g of body weigh from 3,8 g fodder. In conclusion to this experiment, Sońta et al. (2019) argues that the use of duckweed in duck diets was considered advisable.

Another experiment evaluated replacing parts of a mustard oil cake diets with dried duckweed. The control group received 0% duckweed, and the experimental groups received 5, 10 and 15% duckweed. The experiment concluded that duckweed had no significant influence on the body weigh gains, egg weight and feed conversion ratio of the ducks. The increase of duckweed in the diets caused significant deterioration of egg production, but reduced feeding costs, which improved the overall production economics (Sońta et al., 2019).

4.3.2.4 Pigs

Sońta et al. (2019) describes one experiment, where soybean meal was replaced with respectively 20, 40 or 60% dried duckweed. The pigs fed the diet with duckweed mixed in showed overall high body weight gains and feed intake. Experiments with piglets did not show any sign of averse to consuming the diets containing duckweed. Furthermore, the daily body weight gains of the piglets receiving the 40 and 60% duckweed diets, were greater than those of the control animals, receiving normal diet containing soybean as the only source of protein (Sońta et al., 2019). The control group had similar weight gains to the pigs receiving the diet of 20% duckweed. Under long-term feeding, the highest body weight gains was seen from the pigs receiving a diet containing the highest amount of duckweed.

In another test, the control group of pigs (C), were fed sweet potato vines, where the experimental group (E), were fed duckweed (Lemna minor) instead. The pigs in the experimental group consumed around 1,5 kg/day/pig, and had a favorable effect on the body weight gains of the pigs. When comparing the two groups, group E had 27,8% higher body weight and 26,8% better live weight gain, while also having a 18,7% better feed conversion ratio compared to the control group C (Sońta et al., 2019).

Researchers also tried feeding two groups of pigs with different diets. Group C received a diet containing sorghum, soybean meal and a mineral-vitamin mix, while group E received a similar diet, but was supplemented with 10% dried duckweed instead of sorghum and soybean meal. The test showed no significant differences between the groups regarding live weight gain (group C - 730 g, group E - 770 g), with the same thing being seen in the feed conversion ratio (group C - 2,93 kg/kg body weight, group E - 2,96 kg/kg body weight. Final body weight of the pigs was 66,4 kg for group C and 69,8 kg for group E. Thus, it was concluded that adding 10% dried duckweed in a pig ration was beneficial in terms of production results (Sońta et al., 2019).

The results from mixing duckweed into pigs normal diets showed overall greater results that compared to the previously discussed poultry.

4.3.2.5 Ruminants

For this part, the ruminants are comprised of sheep and goats, on which researchers has conducted experiments on, accessing the results of feeding these animals duckweed as part of their diet. Sońta et al. (2019) noted that not enough research was done on cattle regarding the addition of duckweed to their diet.

One test studied the use of duckweed as a feed for Merino ewe (female sheep), in order to determine its effect on the amount and characteristics of the wool. The test was conducted on four groups of sheep, with the control group (C) being fed oaten chaff (700 g/animal/day), experimental group E1 being fed 630 g oaten chaff together with 50 g dried duckweed/animal/-day, E2 being fed 540 g oaten chaff and 100 g/animal/day of dried duckweed, and lastly 630 g oaten chaff and 1 kg fresh duckweed for E3. Sońta et al. (2019) claims that the sheep willingly ingested both fresh and dried duckweed, and the analyzed hair coat parameters (wool yield, rate of wool elongation, fiber diameter) did not differ among the groups four groups. Because of this, the research concluded that duckweed is a valuable source of protein for sheep.

A short experiment aimed at determining if aquatic plants, namely aquatic fern and duckweed, could be potential sources of protein for goats. In the preference test, the researchers noted that goats were more eager to consume fresh as well as dried duckweed than aquatic fern. Based on the results, the authors of the research conducted another test, aiming at examining the nitrogen retention from duckweed supplements, and concluded that there was increased nitrogen retention compared to the control diets, which was based on guinea grass alone (Sońta et al., 2019).

Lastly, a study was made using goats, where they fed the goats dried duckweed instead of soybean meal. Four groups were made: C0, C, E1 and E2, and the diet for all four was based on wheat hay, ground maize, and soybean hulls. The first group, C0, received no soybean meal, but only ground maize and wheat hay, while the goats from group C were only fed soybean meal. Group E1 had access to the feed in which 1/3 of the soybean meal was replaced with duckweed, while group E2 had the same access, but with 2/3 of the soybean meal being replaced with duckweed. The researchers noted no difference in nitrogen intake or excretion, with the same thing being the case for phosphorus, and thus concluded that duckweed is nutritionally comparable to soybean meal (Sońta et al., 2019).

4.3.2.6 Aquacultire - Fish

Experiments were conducted on fish in order to see the effects of using duckweed as a feed ingredient. The first experiment was done with five groups, with one being a control group C and the other four being experimental groups E1, E2, E3 and E4. The control diet contained fish meal, maize, wheat, wheat bran, fish oil, diamol and premix, with parts of the control diet ingredients being replaced with duckweed in the experimental diets. For experimental group 1 and 2, the control diet was replaced with 20 and 40% dried duckweed respectively, and experimental group 3 and 4 having 20 and 40% fresh duckweed replaced from the control group diet. Sońta et al. (2019) argues that no differences were observed in growth rate between groups C and E3, and in other groups, weight gains decreased. In all the groups, feed conversion ratio and protein efficiency ratio[8] were comparable.

Another test were conducted on three groups, a control group C and two experimental groups E1 and E2. Three diets were used, with group C being fed commercial fish fodder, E1 being fed 50% commercial fish fodder + 50% dried duckweed, and E2 being fed 100% dried duckweed. The final body weight and growth rate of the fish were comparable for groups C and E1, with the lowest weight gain and growth rate being observed in group E2. Adding 50% dried duckweed to the fish diet had no negative effect on the fish growth (Sońta et al., 2019).

From the results of the studies cited above, it can be argued that duckweed, either fresh and/or dried, has a potential as a source of protein for farm animals and aquaculture. Seeing that the tests showed mostly positive results, with the exception of broiler chickens, it gives incentive for the use of duckweed as a replacement for soybean, in the diets for the various animals. Soybean is a crop which is already heavily used in various industries, including human consumption and manufacturing of biofuel. This makes duckweed a promising solution since it grows faster, grows where soybean cannot, has a similar protein content of soybean, and is not yet used for industrialized for the manufacturing of human consumption. However, regarding human consumption, Sońta et al. (2019) argues that the Novel Food Catalogue, which is published by the the European Commission, has listed only one representative of duckweed with potential for human consumption; Lemna minor.

The protein content of Lemna minor varies a lot depending on the conditions of which its growing; some conditions being nutrients in the water, temperature of the water, and natural light during growing. It can thus be assumed that the protein content varies depending on where on the globe it grows. Both Maciejewska-Potapczyk et al. (1975) and Maciejewska-Potapczyk et al. (1970) argues that the protein content of Lemna minor grown in Poland is approximately 16% dry based. Majid et al. (1992) and Zaher et al. (1995), in Chakrabarti et al. (2018) argues that the protein content of Lemna minor grown in Bangladesh has a protein content of 14,0 - 20,5% of dry matter. Furthermore, Chakrabarti et al. (2018) argues that the nutritional status of the water body in which the duckweed grows influences the crude protein content of duckweed. The protein content of Lemna minor that was grown i nutrient poor water in India ranged from 9 - 20% in dry matter, whereas it ranged from 24 - 41% in dry matter, in Lemna minor grown in nutrient-rich water. Lastly, Chakrabarti et al. (2018) argues that the protein content of Lemna minor collected from a natural pond in India had a protein content of 28% of dry matter. With this, it can be argued that the protein content varies a lot depending on the nutritional value of the medium of which the duckweed is growing, as well as the temperatures of the area. As temperatures in India and Bangladesh on average are far higher than in Denmark, the higher increase in protein in Lemna minor grown in India, can be argued as being a result of that. However, as described in section 4.3, the optimal temperature for duckweed growth is between 20 and 28°C. The average daytime summer temperature in Poland is approximately 17°C (climate guide, 2021b), with the average daytime summer temperature in Denmark being approximately 19°C (climate guide, 2021a). As the wastewaters of fish farms in Denmark have a high nutritional value, the protein content of Lemna minor grown there can be argued as having a protein content of at least 20% of dry matter or higher.

[8] weight gain of a subject divided by its intake of a particular food protein during the test period

4.3.3 Using duckweed for bioethanol production

As mentioned in section 4.3, the high amount of carbohydrates (14-44%) could make duckweed a good candidate for the use of manufacturing of bioethanol, which can be used as fuel. The growing need for renewable energy production, has sparked an interest in the exploration of production of fuel from more renewable sources, such as agricultural residues. This comes as a result of the limited reserve of crude oil, natural gas and the environmental concerns of using fossil fuels. Unlike fossil fuels is bioethanol a renewable energy source produced through fermentation of starch (carbohydrates), found in biomass, and has been recognised as a potential alternative source of renewable energy, instead of petroleum-derived transportation fuels (Cui and Cheng, 2014).

According to Cheng and Stomp (2009), corn starch is the primary raw material for production of fuel bioethanol in the US, while sugarcane juice and molasses is the most common source in Brazil. In 2019, these two countries accounted for 83% of the global bioethanol production, with table7 showing the total global production of fuel bioethanol in 2019. However, as previously mentioned in section 4.3, corn, soybean and other crops are already heavily used as food and feed resources, thus making way for interests in exploring alternative feed stocks for the production of bioethanol.

Country	Billion litres
USA	59,7
Brazil	32,4
European Union	5,5
China	3,4
Canada	1,9
Rest of world	7
Total	110

Table 7: Global bioethanol production in 2019 (U.S. Department of Energy, 2019)

As stated in section 4.3, duckweed has a carbohydrate content of 14,1 - 43% depending on the species. The variance in carbohydrate content makes some species better for production of bioethanol than others, since a higher carbohydrate amount results in more bioethanol.

Studies have shown that it is possible to increase the starch content of duckweed, by manipulating the growing conditions, such as pH, phosphate concentration and concentration of other nutrients in the growth medium (Cheng and Stomp, 2009; Cui and Cheng, 2014). Doing this could make duckweed species with relatively low amounts of starch a promising source of bioethanol, together with species already having a high amount of starch.

One way of achieving higher concentrations of starch in duckweed is through a process called nutrient starvation. The increase of starch can be stimulated through nutrient deficiency of phosphorus, potassium and/or nitrogen (Cui and Cheng, 2014). When this happens, the nutrient deficiency might lead to a reduced starch use in the cells of the duckweed, resulting in starch accumulation. Water containing very low nutrient concentrations is a good medium for the growth of duckweed with high amounts of starch. Cui and Cheng (2014) argues that a transfer of fresh duckweed from a nutrient-rich solution (such as a wastewater lagoon) to tap water, made the starch content of the Spirodela polyrhiza species increase from about 20% to 45,8% (dry based) after 5 days. Furthermore, a study showed that Spirodela polyrhiza grown at 5°C had a starch content that was 114% higher than that grown at 25°C, and with the increase of daily light, the starch content also increased, together with the increase of temperature (5°C, 15°C, 25°C) (Cui and Cheng, 2014). This shows that lower temperature and higher daily light favours starch accumulation in duckweed. Knowing this, the transfer of low starch duckweed from nutrient rich lagoons to cold tap water basins, and a high amount of light, will be a beneficial way of increasing the starch in duckweed. Should that be the goal of the production of the duckweed.

4.3.3.1 Turning duckweed into bioethanol

Duckweed with high amounts of starch, can be used as a feedstock for bioethanol production. In order to convert the starch/carbohydrates in the duckweed to bioethanol, two processes are needed. Saccharification of the starch/carbohydrates to produce fermentable sugars, and fermentation of the sugars into bioethanol (Cui and Cheng, 2014). The saccharification is done with the use of enzymes, and the fermentation is done with yeast or bacteria (Cui and Cheng, 2014).

Compared to soybean and corn fermentation, duckweed requires little to no mechanical grinding because of the small size of the plant and because of duckweed being such a hydrated biomass. The lack of a milling step that has to be done with corn before the fermentation can be done, results in a substantial saving in energy, one of the major costs in the corn-to-ethanol process (Cheng and Stomp, 2009).

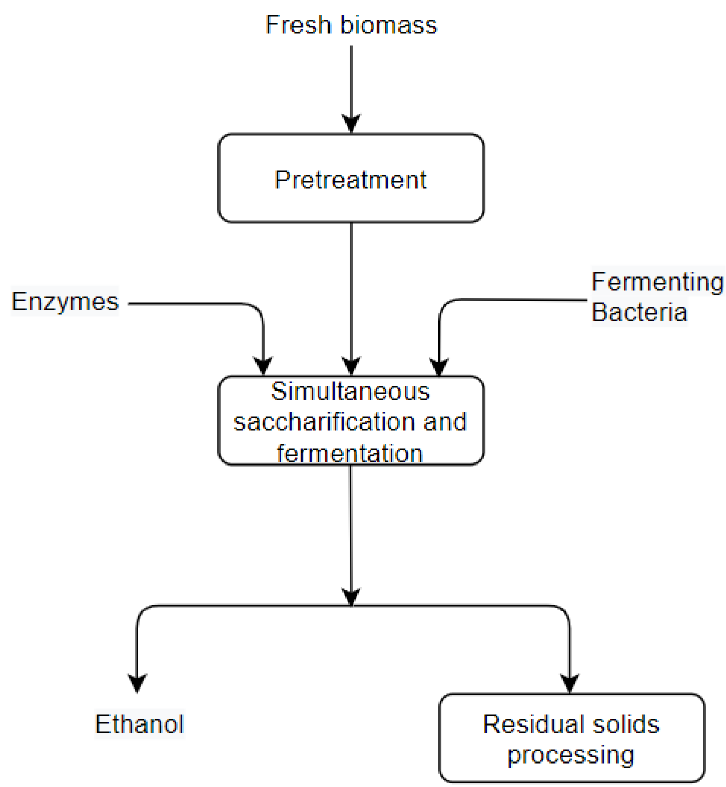


Figure 4: Diagram of bioethanol production from duckweed (Rahman, 2014)

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The above figure 4 is a visualization of the processes that involves the saccharification and fermentation of duckweed into bioethanol, with the use of enzymes and fermenting bacteria. The pretreatment step has the goal of freeing carbohydrates that are trapped in the cells of the duckweed, and also helps break down complex carbohydrates into fermentable sugars for the bioethanol production (Rahman, 2014). Depending on the content of the residual solids, it can either be used as animal fodder if it contains a high amount of protein, or used to produce biogas, which will be discussed in the following section.

Cheng and Stomp (2009) argues that the saccharification of an unmentioned species of duckweed resulted in 509 mg sugars pr. gram of dry duckweed, and fermentation of this sugar using yeast gave a bioethanol yield of 258 mg pr. gram of dry duckweed. Thus making duckweed a biomass that can produce starch in appreciable quantities that can be readily fermented into bioethanol. Based on a study performed by Cheng and Stomp (2009), duckweed could produce starch in a rate of approximately 28 tons/hectare/year, compared to corn starch production of about 5 tons/hectare/year. These results further adds to the point, that duckweed is a favourable biomass that could be used to produce bioethanol, as long as the duckweed species has a high enough amount of starch, either achieved with or without nutrient starvation.

Another study conducted with Spirodela polyrhiza sought to perform saccharification of the duckweed starch into fermentable sugars, for then to ferment the sugars to bioethanol. Firstly, The plant was transferred from nutrient-rich wastewater into well water for 10 days, which resulted in a starch content increase of 64,6% (from 18,8% to 31,0% dry based). The starch was then converted to bioethanol through fermentation, resulting in 94,7% of the starch being converted to bioethanol. According to the researchers, a starch yield of 9.420 kg/hectare/year could be achieved through starch-enriched duckweed cultivation, leading to a bioethanol yield of 6.420 l/hectare/year. This yield is about 50% higher than the bioethanol obtained using corn (Cui and Cheng, 2014). These results furthermore shows that some duckweed species is a promising source for the production of bioethanol, instead of corn-based bioethanol.

Tu et al. (2012) showed increased starch content in Lemna minor, by moving it from nutrient rich waters, to water with zero nutrients. The test was done with varying levels of biodigester effluent in the water, that being 0, 4, 8, 12, 16 and 20% biodigester effluent added to normal water. The results of the test showed that the starch content of the Lemna minor increased the most, when the duckweed was grown in a medium containing 12% biodigester effluent and 88% water (75 mg N/liter). However, the starch content of the duckweed only increased from 2,05% dry matter to 2,63% dry matter (28% increase). The increase of starch as a percentage can be argued to be of notable increase, however, due to the low starch content of the Lemna minor in the experiment, it overall added such a small amount, that the authors argues that Lemna minor is not viable for the manufacturing of bioethanol.

Muztar et al. (1963) and Rakhimov et al. (1981), in Landolt and Kandeler (1987) argues that the starch content of Lemna minor is 4,8% and 5,8 - 8,7% of the dry weight, respectively. Furthermore, Duff and Knight 1963, in Landolt and Kandeler (1987), argues that the glucose amount in Lemna minor is 14%. As glucose is the product of fermentation of starch, this number is also of interest, as it is a sugar that can directly be converted to bioethanol or other biofuels. These percentages are higher than what Tu et al. (2012) reported in their experiment. It is however still notably lower than the starch content of other species, such as Spirodela polyrhiza, reaching a starch concentration of up to 45,8% of dry matter, as a result of nutrient starvation. With the varying amounts of carbohydrates in duckweed species, and with a ranging starch increase from the nutrient starvation treatment, it can be argued that some duckweed species are better for bioethanol production than others. Spirodela polyrhiza would be a better candidate for bioethanol production than Lemna minor, due to the high difference in amount of carbohydrates.

In conclusion, duckweed is a viable candidate for the production of bioethanol, due to its high amount of carbohydrates in some species. Duckweed can be grown at faster rates than traditional crops used for bioethanol. It can furthermore be grown in areas where soil based crops cannot, and requires less mechanical grinding in order to be ready for fermentation, further contributing to duckweed being a viable candidate. The starch content of duckweed species with low starch content, can be increased through nutrient starvation. The results from the nutrient starvation does however vary, and is dependant on the starch content of the species before the starvation. Does the species contain too little carbohydrates, even after nutrient starvation, it can be argued that the species is not suited for bioethanol production.

4.3.4 Using duckweed for biogas production

As stated in section 4.3, the high amount of carbohydrates that is found in duckweed, can be used to produce biogas.

Biogas is an environmentally-friendly renewable energy source, which is produced when organic matter, such as food, animal waste, or crops, are broken down by microorganisms in the absence of oxygen (The National Grid, 2021). This process is known as anaerobic digestion (AD). This process is already occurring naturally, but has been industrialized in order to produce much larger quantities of biogas, than what the natural process can manage.

The feedstock for the production of biogas comes in a wide variety of waste materials, including animal manure, municipal waste, plant material, food waste or sewage. Biogas production can thus be seen as a combined solution that produces energy, while at the same time being a waste treatment technology. The by-product from the production of biogas is a high quality natural fertilizer, ready to be used for the growth of crops (The Danish Energy Agency, 2021). Figure 5 below illustrates the different feedstocks that can be used for the AD process, that produces biogas and digestate respectively.

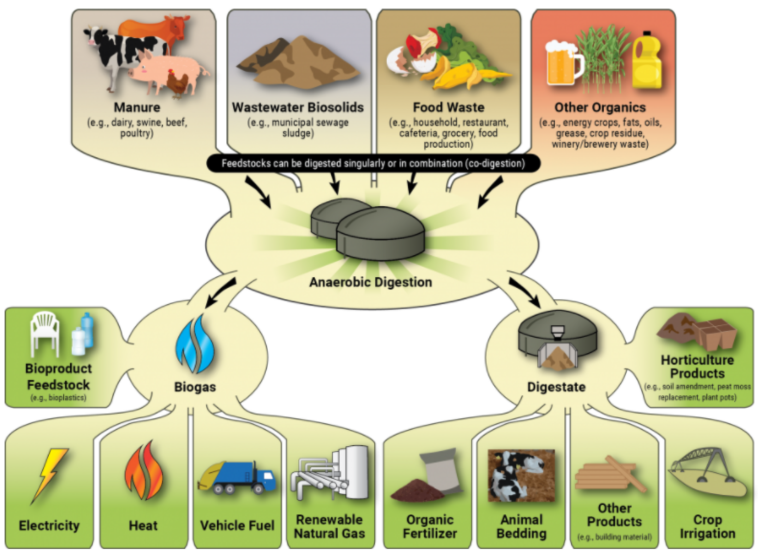

Figure 5: In- and output of anaerobe digestion (United States Environmental Protection Agency, 2021)

The biogas consists mainly of methane (bio methane) and carbon dioxide (CO2), together with small amounts of sulphide and some moisture (The National Grid, 2021). The quantity of the individual materials vary, depending on the type of waste that is involved in the production of the biogas.

The biogas and digestate has its different uses as seen on figure 5. The digestate can be used as organic fertilizer, bedding for animals, crop irrigation [9] and building materials.

According to The Danish Energy Agency (2021), the production of biogas in Denmark has been rapidly increasing, and the total production from 2012 to 2020 was expected to more than triple, reaching a total annual production of 15 petajoule in 2020. In 2012, the majority of the produced biogas was used for electricity (The Danish Energy Agency, 2021). However, the possibilities for usage of biogas expanded, and was in 2020 used in electricity, gas grid, transport, heat, and other processes (The Danish Energy Agency, 2021), as seen in figure 6 page 22.

[9] Crop irrigation is the controlled application of water for agricultural purposes through man made systems, to supply water requirements not satisfied by rainfall (U.S. Geological Survey, 2021)

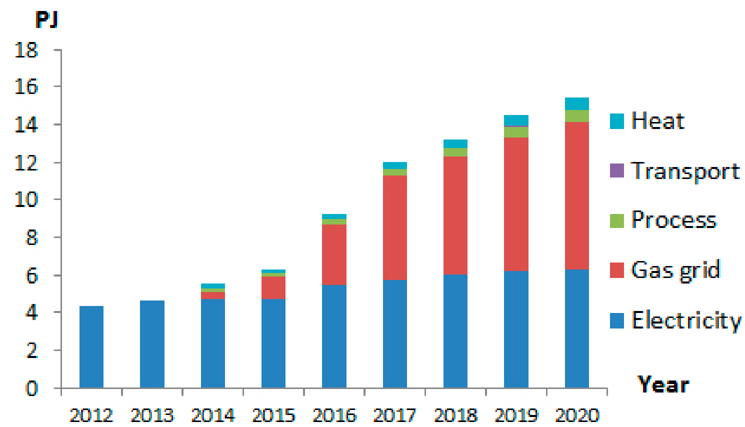

Figure 6: Historical biogas production and use in Denmark 2012-2020 (The Danish Energy Agency, 2021)

The entirety of the biogas produced from 2012-2013 was used for electricity. The production volume was stable in this time frame, possibly due to the introduction of other ways of generating electricity, like windmills. As more biogas was produced, it became more widely used in the different industries, with a major increase of use in the gas grid from 2014 to 2020. With a steady increase in the use of biogas from 2014-2020, it can be expected that the trend will continue, making biogas a continued viable source of energy.

4.3.4.1 Anaerobic digestion

In the process of anaerobic digestion, the organic waste materials found in the biomass, which mostly consists of carbohydrates and protein, is hydrolysed[10] into sugars, fatty acids, amino acids (protein), hydrogen and CO_2. All these components are then fermented by anaerobic bacteria into more CO_2 and hydrogen and acid. The whole anaerobic digestion process is complete when both hydrogen and acid are converted into the methane, that can then be used as biogas. (Cui and Cheng, 2014). Because of the relative low cost of performing this process, as it only requires a sealed container with no oxygen present, biogas production has experienced a large growth in the world in the last few years, especially in Europe, which can also be seen on figure 6.

Cui and Cheng (2014) argues that the addition of commonly available and under-utilised biomass, such as duckweed, could improve biogas production in anaerobic digesters.

A test performed by Clark 1996, in Cui and Cheng (2014), mixed manure and duckweed in a small scale anaerobic digester, and concluded that the addition could increase the production rate of biogas of about 44%. Triscari et al. 2009, in Cui and Cheng (2014) added duckweed to manure using five different concentrations of dry duckweed in the mixed waste. The results of the experiment indicated that the addition of 0,5 - 2% duckweed significantly enchanted the amount of methane and total biogas produced. However, there was no additional increase in the production of methane and total biogas production if more than 2% duckweed was added. Lastly, Huang et al 2013, in Cui and Cheng (2014) mixed manure with duckweed at rate of 1:1. The results showed that the biogas yield of the AD with duckweed mixed in had a biogas production of $1,00\ m^3/m^3/day$, while the control AD only containing manure, had a biogas production of $0,71\ m^3/m^3/day$, thus getting results that indicate that the addition of duckweed significantly improved the production of biogas in anaerobic digestion.

[10]Hydrolysis is the process in which water reacts with a material, to break it down into smaller components (The Editors of Encyclopaedia Britannica, 2021)

As stated in 4.3.3, the process of nutrient starvation of duckweed can lead to the accumulation of starch. Tonon et al. (2017) argues that the potential of duckweed for biogas production is high, due to the high growth rate and high starch content. As starch is such an important component of anaerobic digestion, it can be a viable choice to perform the nutrient starvation, if the purpose of the growing of the duckweed is to use it for the production of biogas. This is furthermore supported by Tonon et al. (2017), that claims that "substantially higher biogas and hydrogen production can be expected if a carbohydrate (starch) enrichment step is included in duckweed cultivation".

Lastly, Henderson et al. 2012, in Tonon et al. (2017) argues that using anaerobic digesters with manure and 2 - 3% added duckweed showed a significant increase in the produced amount of methane, reaching 2.5 times higher results than manure without duckweed.

The addition of duckweed in the process of anaerobic digestion can be argued as having a positive impact on the production of biogas. When duckweed is used for biogas production, it can be of importance to select the species that has a high growth rate, and thus a high capacity for nutrient absorption, while at the same time having a high amount of starch, to maximise the production of biomass.

4.4 Using duckweed in a biorefinery

In the use cases for duckweed described in the sections above, all of them were with the utilisation of raw duckweed, either as an addition to animal fodder, the conversion of raw duckweed to bioethanol, and the addition of raw duckweed to anaerobic digestion for biogas production.

Ambye-Jensen et al. (2017) argues that some bio masses can be used for more than just one purpose such as protein fodder or feedstock for biogas production, but both of them. Using a bio refinery, biomass can be separated into different products, each containing valuable components for the production of protein rich fodder, and feedstock for biogas production. Separating the biomass will result in a product with a high concentration of protein in one product, and a high concentration of carbohydrates in another. These products can then be used as feedstock for protein rich animal fodder, and feedstock for biogas production.

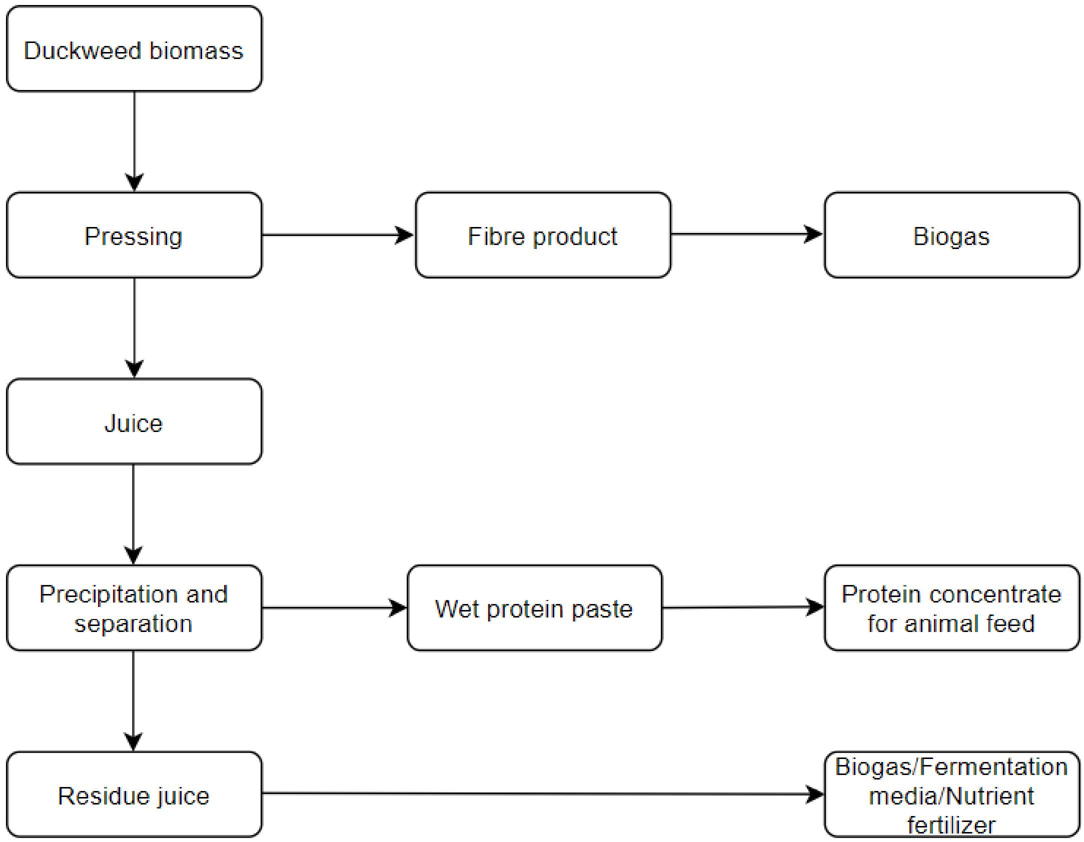

Figure 7: Possible utilisation of duckweed as presented by Ambye-Jensen et al. (2017)

Figure 7 shows the schematic overview of possible products that can be derived from the biorefining of fresh duckweed.

The fresh duckweed is pressed, which separates it into the two products; A fibre product and a juice product. The fiber product contains a still high amount of water and protein, but also a high concentration of carbohydrates, while the juice product also contains a high amount of water, and a high amount of protein.

Ambye-Jensen et al. (2017) argues that a separation process of biomass would normally distribute 50 - 70% of the total dry matter and 40-60% of the total protein into the fiber product together with most of the carbohydrates, and the remaining dry matter and protein pressed out in the liquid juice product. Following precipitation of the juice product, 10-20% of the original dry matter and 30 - 60% of the original protein can then be found in the protein concentrate, which can be used for animal feed, with the rest being present in a residual juice. The ranges of mass and protein is however not ultimate, and depends on the efficiency and technology used in the biorefinery, as well as the biomass used, as different biomass contains different amounts of water and protein (Ambye-Jensen et al., 2017). Should one wish to get even higher concentrations of protein in the protein concentration, one has to optimize the pressing of the biomass, in order to reduce loss of protein in the residual juice and the fibre product.

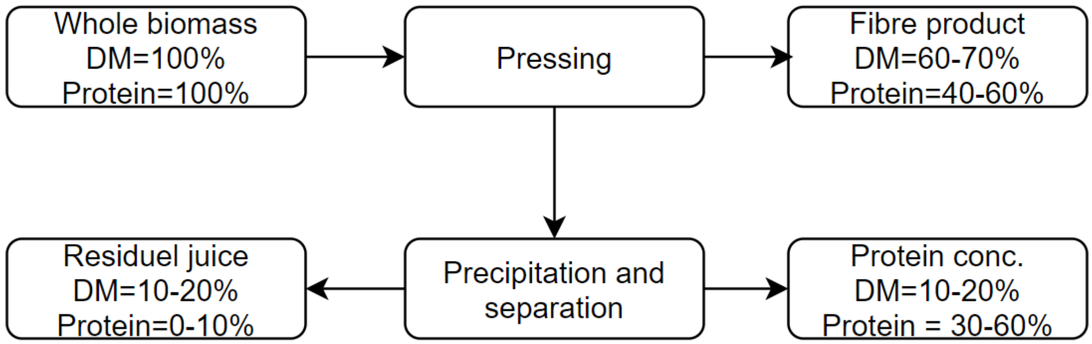

Figure 8: Typical distribution of dry matter and protein in the different fractions following a biorefinery process (Ambye-Jensen et al., 2017)

4.5 Sub-conclusion

Duckweed is a fast growing crop that can be utilised for several different purposes. It is one of the fastest growing plants, and can grow in places where traditional soil grown crops cannot. Its protein and starch content is similar or higher to that of already heavily used crops, such as soybean and corn, making duckweed a favourable candidate to partially replace them for industrial uses. Its industrial uses is the partial adding to diets of animals in agri- and aquaculture, fermentation into bioethanol, anaerobic digestion into biogas, and lastly using a biorefinery to separate the biomass into two products, used for animal fodder and biogas production respectively.

As the duckweed species Lemna minor is the most abundant one in Denmark, it will be the species of focus going forward.

5 Methodology

This section seeks to define the method that was used, and thus the research design and approach for this thesis. The choice of method has a high influence on the thesis, and is critical for answering the research questions that has been presented in section 3

5.1 Research Design

A research design provides a framework for the collection and analysis of data (Bryman and Bell, 2015). In order for the researchers to grasp the many different research approaches that can be applied to the thesis, the research onion model is applied. The research onion is divided into five layers, each employing different options regarding the research approach. The first layer is about the research philosophy, the $2^n d$ about research approach, the $3^r d$ about research strategy, $4^t h$ about the research choices, $5^t h$ about the time horizons and lastly the core about techniques and procedures regarding data collection.

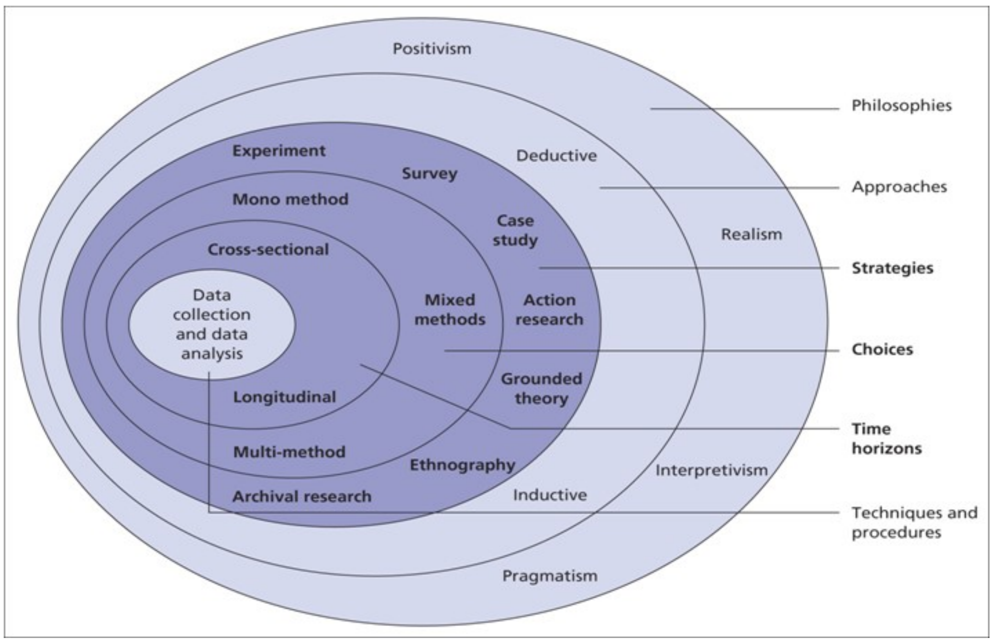

Figure 9: Saunders Research Onion

5.1.1 Research Philosophy

The outermost layer of the onion is regarding the research philosophy that the researchers wants to use. A research philosophy refers to the set of beliefs concerning the nature of the reality being investigated (Bryman and Bell, 2015). Of the different possibilities regarding choice of philosophy, the researchers chose to use the pragmatic approach. The reason for this is that the thesis is a problem-oriented project, which seeks to identify the solution to the problem presented in the problem statement. Pragmatism is often chosen in projects where the researchers makes use of one or more of the research choices in the later layers of the onion (Business Research Methodology, 2021b).

5.1.2 Research Approach

The second layer revolves around how the researchers want to approach the thesis. The three approaches are:

1. Deductive research approach
2. Inductive research approach
3. Abductive research approach

The relevance of hypotheses to the study is the main distinctive point between deductive and inductive approaches (Business Research Methodology, 2021a)

The deductive approach is used if a hypothesis is formulated for the thesis which needs to be confirmed or rejected during the research process. Data is collected in order to help the researchers either confirm or reject the theory developed.

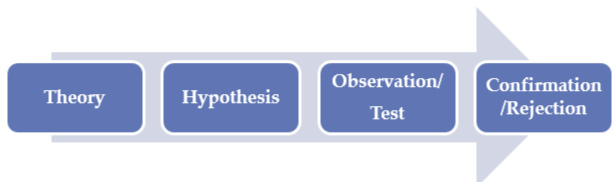

Figure 10: Deductive approach

Alternatively, inductive approach does not involve the formulation of a hypotheses, but starts with research questions and aims and objectives, that need to be achieved or answered during the research process (Business Research Methodology, 2021a). Data will be gathered, for then to look for patterns that can help developing a theory.

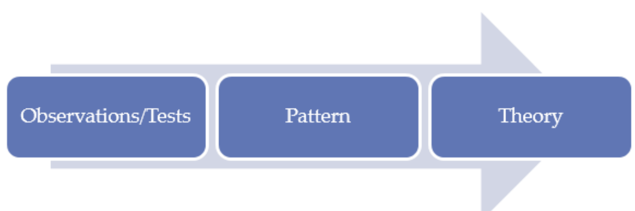

Figure 11: Inductive approach

Saunders et al. (2019) argues that instead of moving from theory do data (as done with a deductive approach) or data to theory (as done with an inductive approach) an abductive approach moves back and forth, in effect combining deduction and induction.

As the researchers has formulated research questions that they seek to answer throughout the research process, the research approach can be said to be inductive. However, since the thesis started out with the idea or theory that duckweed had several industrial uses, the approach could also be seen as deductive. As both approaches are used, it can be argued that the researchers has taken an abductive approach.

According to Saunders et al. (2019), abduction begins with the observation of a 'surprising fact'. To put this statement into the perspective of this thesis, the researchers became aware of the industrial possibilities that duckweed possesses; that of processing duckweed into animal fodder or biofuel. The researchers then seek to work out a feasible way of achieving those industrial possibilities.

Dubois and Gadde (2002) argues that an abductive approach is most fruitful if the objective of the research is to discover new things. While the industrial uses of duckweed for fodder and biofuel has been proposed as long back as 1995 (Leng, Stambolie and Bell, 1995), the researchers was able to find any scientific papers actually showing it applied to any industry yet, but only on an experimental level. Any Danish biorefineries or manufacturers of animal fodder that the researchers have contacted, have neither used duckweed in their manufacturing. Because of this, the purpose of this thesis; that of working out a feasible way to utilise the duckweed growing on wastewaters, can be argued as "discovering new things". Taking the abductive approach was therefore a reasonable choice for this thesis.

5.1.3 Research Strategy

The third layer revolves around the choice of research strategy, which is about how the researchers intend to carry out the work. As seen in figure 9, some of the strategies are survey, case study and experiments. The researchers choose to use a case study, since the basic case study entails the detailed and intensive analysis of a single case. A case study strategy has the capacity to generate insights from intensive and in-depth research into the study of a phenomenon in its real-life context, leading to rich, empirical descriptions and the development of theory (Saunders et al., 2019). To achieve such insights, a case study research draws on qualitative and quantitative data from a range of sources, in order to understand the dynamics of the case. Choosing a case-study enabled the researchers to focus on one specific topic throughout the thesis, allowing them to gain in-depth knowledge about the area of interest, namely the potential industrial uses of duckweed, and how BioMend can realise that potential. The case study is based on the hypothesis that duckweed, more specifically Lemna minor, can be used to manufacture animal fodder and/or bio-fuel.

5.1.4 Research Choices

The fourth layer revolves around the choice of research that the researchers will conduct. As both quantitative and qualitative methods exists, the researchers would have to choose between using only one of either, or using both. Mixed methods, is used as a simple shorthand to stand for research that integrates quantitative and qualitative research within a single project (Bryman and Bell, 2015). As the researchers collected both quantitative and qualitative data throughout the thesis, the research choice was mixed methods. Doing this ensured that the researchers would have a sufficient amount of data to answer the research questions, as both forms of data can prove to be crucial for the correct answering of the research questions.

5.1.5 Time Horizons

The fifth layer revolves around the time horizon of the thesis. The time horizon can be categorized into two categories: Cross-sectional and Longitudinal. A cross sectional study is chosen when researchers want to conduct a study in a short amount of time. These studies does often not take longer than a couple of months. A cross-sectional design entails the collection of data on more than one case (usually quite a lot more than one) and at a single point in time in order to collect a body of quantitative of quantifiable data in connection with two or more variables (usually many more than two), which are then examined to detect patterns of association (Bryman and Bell, 2015). A longitudinal design is chosen if the project is a long term study, often taking several years to complete, and is most often coupled with an ethnographic method. Because of the length, a longitudinal study collects data multiple times over the course of the study, compared to the cross-sectional which only collects data once. For this thesis, a cross-sectional time horizon was chosen. The reason for that being that the project is limited time-wise to a single semester, stretching over four months. However, the researchers would be collecting data multiple times during the period of the thesis writing. This was done through interviews with relevant people, and through literature search. This does go against the characteristics of a cross-sectional design, which only collects data at one point. However, as the researchers would continue to develop the thesis throughout the duration of the semester, new data would be needed, and thus new literature would be found, together with new relevant persons for possible interviews.

5.1.6 Techniques and Procedures

The final layer, or the core of the onion, revolves around the practicalities of data collection and analysis. The choices made in the previous layers of the onion will have an impact on the procedures. As stated in 5.1.4, the researchers used mixed methods, resulting in both qualitative and quantitative data being acquired. Furthermore, this layer revolves around the choice of data collection methods, sampling and analysis that the researchers made use of, in order do adequately answer the research questions that has been stated in section 3.

5.1.6.1 Data Collection and Data Analysis

The following section seeks to describe the different ways that researchers collected data, as well as the difference between qualitative and quantitative data, and the advantages and disadvantages that comes with them.

5.1.6.2 Primary and Secondary Data

When it comes to collection of data, there are mainly two ways of doing so: Primarily and secondarily. The difference between the two is dependant on who collected the data. Primary data is data that has been collected by the researchers themselves, and secondary data is the use of data that has been collected by some one else at a previous point in time (Bryman and Bell, 2015). For this thesis, the researchers collected and made use of both primary and secondary data.

5.1.6.3 Qualitative Data

Qualitative data is data that is acquired through interviews, participant observations, and literature (Bryman and Bell, 2015). The researchers collected qualitative data throughout the project, both primarily and secondarily. The primary qualitative data was collected from conversations and semi-structured interviews with relevant people from biorefineries, organisations working with biofuel, fish farms etc. Secondary qualitative data was acquired in the form of literature that had relevance for the thesis.

5.1.6.4 Quantitative Data

Quantitative Data is data regarding numbers and measures (Bryman and Bell (2015)). This form of data will be important when assessing the use cases of duckweed, as the properties of duckweed, that is the protein and carbohydrate content, as well as the growth rate, vary depending on the environment, and time of year (Goopy and Murray (2003)). Quantitative data was collected both primarily and secondarily as well. The primary quantitative data was acquired from semi-structured interviews. Secondary quantitative data was acquired from literature, containing data about the properties of duckweed such as protein and carbohydrate content, the ideal conditions for growth etc. Another form of secondary quantitative data that was acquired, was numerical data regarding the prices affiliated with duckweed harvest, transport and processing, as part of the analysis, that is written in section 6. This secondary data was acquired through interviews with industries working with biorefinering, transportation, and harvest of bio matter.

5.1.6.5 Interview

Interviews was conducted with key persons of interest to the researchers and the thesis, as part of the data collection. Interviews vary depending on the approach taken by the interviewer. The two most common types are:

1. Unstructured Interview
2. Semi-structured Interview

In an unstructured interview, the researcher uses at most a note with some pieces of information for the interview. There can be just a single question that the interviewer wants to ask, to which the interviewee responds in any way they see fit, and the interviewer then responds to points they find interesting, thus wanting to follow up on. Unstructured interviews tend to be similar in character to a conversation (Bryman and Bell, 2015).

A Semi-structured interview is a bit different, with things being a bit more controlled, in the way that the researcher has a list of questions that has been prepared before the interview, on a fairly specific topic. It is in the interest of the interviewer that the interviewee answers the questions, but the interviewee has a great deal of leeway in how to reply (Bryman and Bell, 2015). Because of this, the interview is very open, and questions that was not prepared may be asked if the conversations changes to another, albeit still relevant topic.

The researchers conducted semi-structured interviews. The decision to do this was made due to the fact that people with knowledge about duckweed and its uses for either animal fodder or bio-fuel was relatively scarce, especially in Denmark. Because of this, the researchers wanted the interviews to be as open as possible, but still within the area of interest, as the information regarding uses of other biomass can be of value, and applicable to the use of duckweed in the different industries, such as animal fodder, bio-ethanol, or biogas. Furthermore, the current pandemic was making it difficult to meet up in person to conduct a physical interview, and thus forced the researchers to instead conduct most of the interviews over a phone call. The researchers did manage to conduct one physical interview with Peter Holm, who is the owner of several fish farms. When conducting a semi-structured interview over a phone call, the persons that the researchers wished to interview was contacted in advance to make sure that an interview will be possible. They wold also get a brief explanation of the scope of the interview, in order to assure that the topic for the interview was well defined and understood for both parts. The interviews were performed in Danish as the persons contacted are from Denmark. The purpose of the interviews was to gain knowledge about duckweed and its potential uses.

The first semi-structured interview was with Peter Holm, who is a fish farmer, and chairman of Danish Freshwater fish farms. The interview had a duration of 45 minutes, and can be read in full in appendix A.1 The goal of the interview was to gain knowledge about the logistical possibilities of harvesting duckweed at the lagoons present at fish farms, and what industrial possibilities that he saw, with the removal and utilisation of duckweed.

The second semi-structured interview was with Morten Ambye-Jensen, who is a professor in bio and chemistry technology at Aarhus University Foulum. He also works at Foulum Biorefinery. He has done several papers and projects on bio refining of several bio materials, and was of great interest to interview with the goal of gaining knowledge about the industrial possibilities that duckweed have. The interview had a duration of 20 minutes, and can be read in full in appendix A.2.

The third semi-structured interview was with the Commodity Responsible manager at Biorefine Denmark, Robert Mouritsen (appendix A.3). He is responsible for all contracts with farmers delivering grass for the production. As well as the quality of the delivered products. He has been working at Biorefine Denmark since December 2020, and the production of biorefining grass began in April 2021.

#	Organization	Name	Role	Interview goal	Interview form
1	Dansk Akvakultur	Peter Holm	Chairman	Insight into the logistics of harvesting duckweed, and his own interests in the removal of duckweed from his lagoons	Semi-structured interview
2	Aarhus Universitet Foulum	Morten Ambye-Jensen	Professor	Insight into the industrial possibilities of duckweed	Semi-structured interview
3	Danish Methanol Association	Lars Thomsen	President	Insight into the market of biogas and if he saw potential in duckweed as a feedstock for biogas	Conversation
4	Haarslev	-	Support	Information about prices of products capable of handling fresh duckweed	Conversation
5	Teknologisk Institut	Bodil Pallesen	Senior Advisor	Knowledge about harvest of duckweed	Conversation
6	Nature Energy	Jacob Lindhardt Palm	Biomass purchaser	Information about the sales/purchase prices of biomass for biogas production	Conversation
7	Energistyrelsen	Rune Kvols Rasmussen	Fuel Regulation	Information on regulations on production of biogas	Conversation
8	Biorefine Danmark	Robert Mouritsen	Raw material Manager	Insight into the biorefining of biomass	Semi-structured interview
9	Vognmand Per Nielsen a/s	Per Nielsen	Haulier	Information regarding the pricing of transport	Conversation

Table 8: Interviews conducted for the thesis

The persons interviewed was found in different ways. Some were known by the researchers themselves, like Peter Holm, while some were recommended by others, and some were found by the researchers as part of data collection for the thesis.

The questions for the interviews were prepared in different ways, as the interviewees had different backgrounds and knowledge about the scope of the interview. The questions for the interview with Peter Holm were formulated more openly and not as complex compared to the interview with Morten Ambye-Jensen. The reason for this being that the researchers were not that far in the thesis at that point in time, and was still in the process of defining relevant areas for the possibilities of duckweed. The open questions ensured in open answers, which served to broaden the amount of information the researchers got from the interview.

At the point of time that the interview with Morten Ambye-Jensen happened, the researchers were further ahead in the thesis, and had already narrowed down the industrial uses of duckweed, to that of animal fodder and biofuel. This resulted in the questions to Morten Ambye-Jensen being more specific, as they seeked to gain specific knowledge that he had regarding the biorefining of biomass.

Both interviewees were informed that the interview was being recorded for the purpose of the researchers being able to analyze the interview afterwards.

5.1.6.6 Reliability and Validity of the Research

Reliability and validity are important criteria when it comes to assessing the quality of the research being conducted by the researchers (Bryman and Bell, 2015). Reliability is fundamentally concerned with the consistency of the. Thus, if a study is inconsistent and then also unreliable, it can result in the overall study being of lesser quality. Validity is regarding whether or not a measure of a concept really measures that concept (Bryman and Bell, 2015).

One way to ensure validity is to use Face validity. Face validity is used when one asks other people whether or not a measure seems to be getting at the concept that is the focus of attention (Bryman and Bell, 2015). This can be done in an interview, where the interviewer asks the interviewee, which is an expert on the topic, whether or not he or she thinks a measure seems to reflect the concept concerned.

In order to assess the reliability of an interview, the researchers would have to consider the possibility of any of the participants being biased in any way, or if the one(s) being interviewed could in some way be unreliable. If none were biased, the reliability increased. One way for the interviewers to avoid or reduce the chances of bias, was to make sure that the questions for the interview were formulated correctly. This also ensured that the questions were not ambiguous in any way, which could end up in misunderstandings from the perspective of the one being interviewed.

To ensure that the reliability of the research was high, the researchers made sure to interview key persons with high knowledge about the area of which they are interviewed, such as Morten Ambye-Jensen having a PhD in bio-technology, and Peter Holm being a fish farmer, as well as being chairman of the freshwater fish farms. Thus having a great amount of knowledge about the utilisation of biomass, and the impact that the growth and harvest of duckweed have on fish farmers, respectively.

Furthermore, to ensure that the consistency of the research being conducted was high, the researchers made use of multiple sources for each topic that was researched, such as the results achieved by numerous authors from the use of duckweed for the feed of multiple animals, the results achieved by numerous authors from the use of duckweed in anaerobic digestion to biogas production etc.

Lastly, the researchers have multiple times used face validity during the interviews in order to assure the validity of the research being conducted. One of the ways this was done was the confirmation from the interviewee that the utilisation of duckweed indeed was possible for the use of protein rich fodder, and as a feedstock for the production of bio-energy, thus also giving a valid reason for the researchers to continue with the project.

5.1.6.7 Delimitation of the Research

For the scope of the thesis, some delimitation's has been made. As described in 4.3, the Lemnoideae (duckweed) is made up of several species, where this thesis will focus on Lemna minor, as it is the most abundant one in Denmark, and the one that grows on the lagoons of fish farms. Furthermore, as the researchers are studying a management oriented master, the biological and chemical processes and descriptions involved in the use of duckweed for its various industrial purposes, will not be discussed or explained in any more detail than a short explanation of the word or phrase. Furthermore, the thesis will not involve the actual processing of duckweed, that being the harvesting, measure of chemical content, sale, or biorefining. The researchers will make assumptions about some processes based on available data from sources like literature and interviewees. This includes the growth rate of duckweed, the sales price of duckweed to biorefineries based on information acquired by Robert Mouritsen and Morten Ambye-Jensen, the amount of money needed to invest in the machinery for harvesting and transport of fresh duckweed etc.

6 Analysis

The analysis is divided into several section. The first revolves around the aquaculture industry in Denmark, more specific the fish farms, as this is where Lemna minor grows. Secondly will the analysis revolve around the potential Danish customers for duckweed, that can utilise it. Thirdly will the analysis revolve around the most feasible use case and value chain for the utilisation of duckweed. Lastly, a business case for the value chain and proposed solution for the utilisation of duckweed.

6.1 The source of duckweed in Denmark

This thesis will determine the best usage of duckweed that can be harvested from Danish fish farms lagoon areas. The focus of this section is to examine the industry of Danish fresh water fish farms. After that, is the growth potential of duckweed calculated. Lastly is the total potential harvest area and mass calculated.

6.1.1 Aquaculture industry in Denmark

The freshwater aquaculture industry in Denmark is an industry with a total of revenue of more than 1 billion DKK in 2018(Statistics Denmark, 2020b). As seen in table 11 page 34, the industry of fresh water fish farms is small in number, with a total population of 151 fish farms in 2019. The industry is divided into three smaller segments[11]. All three segments are subject to the same legislative framework.

The legislative framework is the "Executive Order on environmental approval and simultaneous case processing of freshwater fish farms" (Ministry of Environment & Food, 2016). With the Executive Order, the fish farmer can follow one of two environmental approval methods. The first method is the traditional "Feed Quota Approval", that is an individual evaluation based on the location of the fish farm. The reason for this evaluation, is to mitigate the environmental impact of nutrient emission from the fish production. In Ministry of Environment & Food (2016) the emitted nutrients is calculated through a standard emitting factor pr. ton fodder used in the production, see table 9.

Nutrient	Standard emission (kg/t fodder)
Ammoniacal nitrogen	39
Total nitrogen	56
Total phosphorus	4,9
BOD[12]	97

Table 9: Standard emission pr. kg fodder used in fish production (Ministry of Environment & Food, 2016)

To receive the environmental approval, the local freshwater stream is analysed by the local region. This will serve to determine the maximum nutrient emission allowance. From this maximum emission, can the nominal yearly fodder usage, in the production, be calculated.

The fish farm is required to cleanse the excess water to a specific degree of purification. The required degree of purification, is fixed by the size of the fish farm as seen in table 10. The more strict requirements to larger fish farms will ensure that the accumulated nutrient emission is more evenly spread out, despite the size of production. It is typically the segment of "traditional fish farms" that follows this type of environmental allowance.

[11] Market analysis and market segmentation provided by Co. writer of this thesis K. K. Hansen (2021)
[12] Biochemical Oxygen Demand

Production size	$0-25t$	$>25t$ **to** $\leq 230t$	$>230t$
Ammoniacal nitrogen	47%	55%	65%
Total nitrogen	50%	50%	50%
Total phosphorus	60%	65%	70%
BOD	60%	75%	85%

Table 10: Legislative requirements to water purification degree (Ministry of Environment & Food, 2016)

The second type of environmental approval is the "Emission Based". This was introduced in 2016 in the Executive Order for fish farms (Ministry of Environment & Food, 2016). The basis of this type of environmental approval is again fixed at the maximum emission allowance for the specific freshwater stream. But Emission Based environmental approval does not specify a specific degree of water cleansing of the excess water. This allow (and encourage) the fish farmer to increase the total fish production significantly, by increasing the following water cleansing to a higher degree. The total fish production can be up-scaled as long as the nutrient emission remain below the allowed level.

The fish farms that typically utilise the Emission Based environmental approval, is the farms in segments Model type 1 and Model type 3. These two segments have a higher degree of water re-circulation, thus will these fish farms have to manage a lower total volume of water. There are theoretically an opportunity for fish farmers to construct a Model type 2 fish production. But none of these have proven financially viable in Denmark. It can therefore be seen in table 11, that this segment does not exist. A consequence of the Emission Bases approval is that more fish farms has invested in methods to manage their nutrient emission. This can be seen in the value and production increase of the two segments of Model type 1 and 3, in table 11. At the same time has the number of fish farms in the segments remained stable.

Segments	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Traditional fish farm											
Population	189	177	162	157	157	145	138	131	127	123	118
Yearly production (t)	15.285	14.841	14.425	16.474	15.523	15.925	15.214	14.512	15.112	13.323	13.364
Value (1.000DKK)	323.673	301.196	319.891	340.510	328.005	370.713	380.109	356.858	393.588	346.102	343.321
Model type 1											
Population	14	19	17	16	17	17	17	18	17	17	17
Yearly production (t)	961	1.506	2.667	2.967	3.119	3.086	3.853	3.747	4.293	4.586	5.166
Value (1.000DKK)	16.812	31.410	53.566	56.375	60.684	64.402	86.011	85.208	100.184	108.928	122.770
Model type 3											
Population	11	13	13	13	16	15	16	17	16	16	16
Yearly production (t)	4.317	6.423	7.001	7.620	9.025	8.198	9.373	8.996	8.769	8.737	12.389
Value (1.000DKK)	67.081	110.567	133.166	97.257	170.231	168.962	207.591	196.508	196.156	194.211	278.611
The industry in total											
Population	214	209	192	186	190	177	171	166	160	156	151
Yearly production (t)	20.563	22.770	24.093	27.061	27.667	27.209	28.440	27.255	28.174	26.646	30.919
Value (1.000DKK)	407.566	443.173	506.623	494.142	558.920	604.077	673.711	638.574	689.928	649.241	744.702

Table 11: Overview of the Danish fish farm industry(Statistics Denmark, 2021)

The total industry has declined in numbers since 2009, but especially the segment of traditional fish farms. This is the segment that in most cases rely on direct flow of water from a freshwater stream and minimum amount of re-circulation. The technology used for the production is the least advanced of the three segments. Because of the production mechanisms utilised in this segment, the investments can be kept lower than the other two segments. Although the segment of Traditional fish farms has seen a decline in population from 2009 to 2019 of more than 37%, production only declined by 12,5% but saw a segment value increase of 6%.

Both segments of Model type 1 and 3 has seen an increase in population since 2009. With this increase, has the yearly production and value seen a drastic increase. Fish farms in these two segments are usually older traditional types, that have needed to rebuild in order for the fish farm to meet the legislative requirements. The segment of model type 3 is the most technological advanced. This type of production, can produce a significantly larger amount of fish on the same area than other types of fish farms. This can be seen in the yearly production for the segment of Model type 3. This segment produces 40% of all the fish produced in 2019. This is done by only 10,6% of the fish farmers in the industry.

The trend in the industry is fever and larger production facilities with a huge focus on methods to reduce nutrient emission in the excess water.

For a deep dive in the marked analysis and marked segmentation of the fish farm industry, see appendix F

6.1.2 Annual duckweed growth

The growth rate, composition, and amount of Lemna minor, is dependent on several factors. These include the nutrient concentration (nitrogen and phosphorus) in the water in which it grows, the temperature and pH, sun exposure and day length, and lastly wind speed, as stated in section 4.3

The approximation of the annual growth of duckweed on the lagoon areas of the fish farms will utilise the Sigmoid function as a basis of the calculation (Uin et al., 2003). The function utilise time as a variable for the beginning, maximum and end of growth. These factors are defined by the temperature in Denmark. Uin et al. (2003) shows how the organic growth typically follows a unimodal bell-shaped curve[13] beginning in the spring as the temperatures exceed five degrees. The curve will drop to zero in the fall when the temperatures drops below the required level. The total yearly growth can be calculated by using equation 1.

$$\frac{dw}{dt} = c_m \left[\left(\frac{t_e - t}{t_e - t_m} \right) \left(\frac{t - t_b}{t_m - t_b} \right)^{\frac{t_m - t_b}{t_e - t_m}} \right]^{\delta} \tag{1}$$

Where c_m is the maximum growth rate for the duckweed, at the time t_m. t_b and t_e is the beginning and end of the growth season respectively. t is the time. Lastly is the δ a fixed parameter set to 1, according to Uin et al. (2003).

The input parameters used in equation 1 are based on a number of assumptions regarding the temperature development throughout the year. As described in section 4.3.3 duckweed will not have any significant growth at temperatures below $5°C$. Therefore, the first assumption is that there will only be calculated for growth in months with an average temperature above $5°C$. The second assumption is that the best growth rates of duckweed is the month with the highest average temperature. In section 4.3.3 is it explained that duckweed has higher growth rates at higher temperatures up until $29°C$. The third assumption in the calculation is the growth rate. Lemna minor has a growth rate between 3,5 - 14,1 $g/m^2/day$ in dry weight (Ge et al., 2012), or a growth rate between 87,5 - 352,5 $g/m^2/day$ wet matter, based on Lemna minor containing 5% dry matter (Nørgaard et al., 2021). This interval will provide the basis of respectively the conservative and liberal estimation of the yearly growth rate pr. squire meter (c_m).

In equation 1, three specific days are defined. The beginning and end of duckweed's growth season and the time with the highest growth rate. The average temperature for each month in year 2011-2020 will be used, see table 12. Note that the min. and max. temperature is not the average min. and max. throughout the years from 2011-2020. Instead is it the lowest and highest temperatures recorded in this time frame.

[13]The bell-shaped curve has a single vertex

Month	Lowest (°C)	Highest (°C)	Average (°C)
January	-17,6	12,1	1,89
February	-23,1	15,8	1,76
March	-15,0	21,5	3,70
April	-8,6	26,7	7,41
May	-4,5	29,3	11,66
June	1,1	32,7	14,91
July	1,8	33,1	16,70
August	2,8	33,6	16,84
September	-1,3	29,9	13,88
October	-5,7	26,9	10,11
November	-9,9	17,7	6,25
December	-16,5	13,4	4,15

Table 12: Average monthly temperature in Denmark 2011-2020 (Danish Meteorological Institute, 2021)

Based on the average temperature during the year, it can be assumed that the growth season starts in mid April (t_b) and ends in mid November (t_e). The month with the highest average temperature is August. The time with the highest growth rate will be mid August (t_m). The two calculations in equation 2 and 3, is the conservative and liberal annual weight of duckweed pr. square meter (w) respectively.

$$w_{conservative} = \int 87,5\left[\left(\frac{319-t}{319-243}\right)\left(\frac{t-105}{243-105}\right)^{\frac{243-105}{319-243}}\right]^{1} dt = \underline{10.884,50g/m^2/year} \quad (2)$$

$$w_{liberal} = \int 352,5\left[\left(\frac{319-t}{319-243}\right)\left(\frac{t-105}{243-105}\right)^{\frac{243-105}{319-243}}\right]^{1} dt = \underline{43.848,97g/m^2/year} \quad (3)$$

A graphical representation of equation 2 and 3 can be seen in figure 12 page 37.

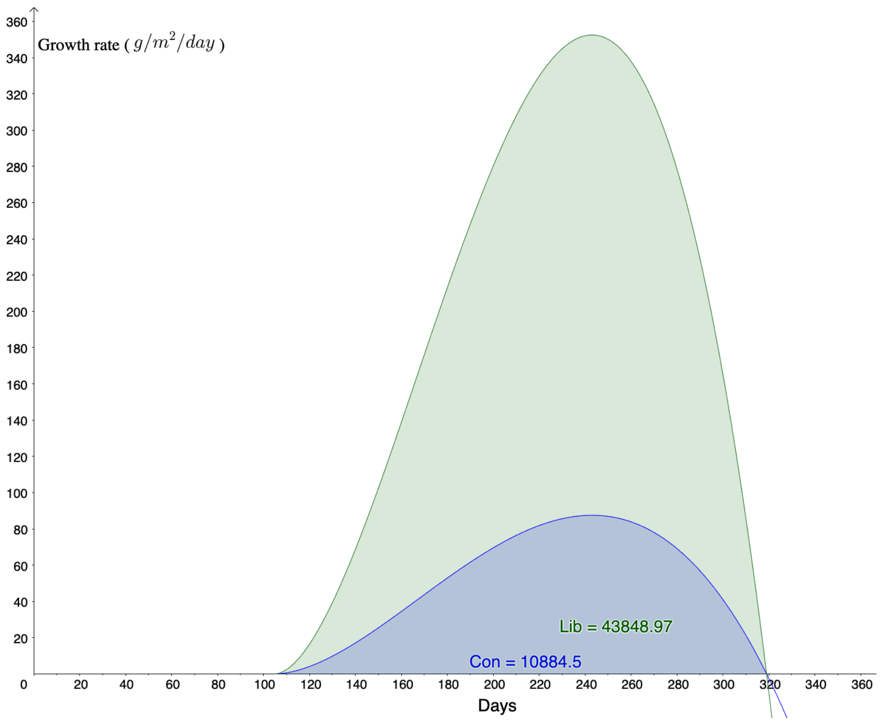

Figure 12: Annual growth of duckweed pr. square meter

6.1.3 Duckweed production in Denmark

The growth of Lemna minor on the lagoon areas at Danish fish farmers is estimated through the annual growth from section 6.1.2 and information on the legislative requirements. According to Peter Holm[14], do neither the interest organisation Danish freshwater Aquaculture or the ministry of environment hold a record of the total surface area of lagoons. The calculation of the total lagoon area is based on the assumption that the fish farmers follow governmental guidelines and legislation for minimum lagoon size in regards to the production. The requirements to the lagoon size differs in the three segments of fish farms. In table 13, the minimum requirements for lagoon areas in the three segments can be seen. Furthermore, is the total lagoon area in Denmark calculated to just above 1,1km^2.

Production type	Production size in segment (t/y)	Required size of lagoon (m^2/t)	Lagoon area (km^2)
Traditional fish farm	13.364	32,5	0,434
Model type 1	5.166	60,0	0,310
Model type 3	12.389	28,8	0,357
Total lagoon area			1,101

Table 13: Legislative requirements to lagoons (Ministry of Environment & Food, 2016)

The total potential biomass production of duckweed on the lagoon areas of fish farms can be calculated by using the conservative and liberal estimation of the yearly production of duckweed (equation 2 and 3). In table 14, the estimated duckweed production can be seen for each of the three segments, as well as the total potential.

[14]Chairman for Danish freshwater Aquaculture

Production type	Lagoon area (km^2)	Conservative production (kg/y)	Liberal production (kg/y)
Traditional fish farm	0,310	4.727.465	19.044.923
Model type 1	0,310	3.373.760	13.591.427
Model type 3	0,357	3.883.624	15.645.453
Total growth	1,101	11.984.849	48.281.803

Table 14: Total duckweed production

In order to assess whether or not the growth rate calculated in equation 2 and 3 is representative, it is of interest to compare this growth rates observed by other authors.

Cheng and Stomp (2009) argues that they have achieved an almost constant growth rate of 0,2kg dry weight/m^2/week from the growth of the duckweed species Spirodela punctata in wastewater research. Converted to fresh matter in g/m^2/year, that equates to 114.000g/m^2/year. This growth rate is substantially higher than both the conservative and liberal estimate calculated further above. However, as it is stated, the growth rate achieved by Cheng and Stomp (2009) was in wastewater research, so it can be argued that the growth was under a controlled environment, and as the species growth is a different one than Lemna minor, that can also have an affecting role.

Furthermore, Oron et al. (1988) achieved dry matter growth rates between 8.6g/m^2/day and 14.3g/m^2/day from duckweed grown on domestic waster water treatment ponds in Israel. Converted to fresh matter in g/m^2/year, that equates to 34.314g/m^2/year and 57.057g/m^2/year respectively. These growth rates are more approximate to the growth rates calculated for Lemna minor in equation 2 and 3, namely being 10.884,50g/m^2/year 43.848,97g/m^2/year. With the difference in these two scenarios being the higher temperature in Israel, and the over all assumed lower nutrient concentration of domestic wastewater, compared to fish farm lagoons, it can be argued that the numbers calculated for the growth of Lemna minor in Danish fish farms are representative. Se table 15 for the comparison of yearly growth in literature and the calculated growth from equation 2 and 3

Author	Growth rate
Cheng and Stomp (2009)	114.000g/m^2/year
Oron et al. (1988)	34.314g/m^2/year - 57.057g/m^2/year
Calculated estimate	10.884,50g/m^2/year - 43.848,97g/m^2/year

Table 15: Comparison of calculated estimated growthrate with other authors

6.1.4 Specific value creation for fish farmers

As the source of duckweed is the Danish fish farms, it is investigated what benefits this industry will see from a collaboration with BioMend, in the removal of biomass from the lagoon areas. As fund in section 2.4.1the removal of biomass from the lagoons will provide a reduction of total nutrient emission from the fish farm. There are two main reasons why this is desirable for the fish farmers.

The first reason is that the total annual allowance of nitrogen emission from the aquaculture industry is 850t by the end of year 2021 (Ministry of the Environment & Food, 2015). The problem for the industry is that the emission in 2018 was about 1.040t (Ministry of the Environment & Food, 2019)[15]. The current emission level is almost the same as the emission in 2007 (see appendix E). This means that the industry needs to find new solutions to reduce the total nutrient emission.

[15]The public data for 2019 and 2020 has not been published yet, in part due to CoVid-19 related delays

The second reason for the industry to utilise a new solution to reduce nutrient emission, is the potential industry growth. In section 6.1.1, it was found that the Emission Based environmental approval allow the fish farmer to increase the production significantly as long as the fish farmer are able to manage the additional nutrient emission. This type of growth would be considered organic growth.

It should be mentioned that it is possible for the fish farmer to increase the production through acquisition of nearby fish farms and there feeding quotas. However, growth though acquisition is expensive for fish farmers in Denmark due to the financial act of 2016 Ministry of Environment & Food (2021). From 2016 and forward, the danish government began to make acquisitions of fish farms. The price paid by the government is considered to be above market price. The goal of this is to reduce the number of active fish farms. When the government has bought a fish farm, the feeding quotas will not be available for nearby fish farmers to obtain. This means that the total nutrient emission for that part of the water stream will be reduced going forward.

In the interview with Peter Holm (appendix A.1), the emission from Danish fish farmers was discussed. He argues that both the nitrogen and phosphorus emission can be a problem for the individual fish farmer. One of the biggest risks for a fish farmer is the insufficient management of nutrient emission. A fish farmer on the Feeding quota approval will have to report values of nutrient emission levels six times a year. Where a fish farmer on Emission Based approval have to report emission values 26 times a year. If the reported values for nutrient emissions continuously exceeds the permitted level, the fish farm will in worst case be closed by the government Ministry of Environment & Food (2016).

It can be concluded that the industry of fish farmers have a clear incentive to manage the nutrient emission and invest in methods to achieve this. According to Peter Holm will it be reasonable for fish farmers to pay about 10 DDK/kg nitrogen and 50 DDK/kg phosphorus removed from the lagoon. The reason for the difference in price is tied to two main reasons. Availability of the two nutrients and the difficulty of removal. In the excess water from fish farms will there be more than ten times as much nitrogen in the water compared to the phosphorus concentration Ministry of Environment & Food (2016). The water cleansing methods utilised at the fish farms today are better for nitrogen removal than phosphorus (K. K. Hansen, 2021).

6.2 Potential Danish customers for duckweed

As concluded in section 4.5, duckweed is able to be used for several different industrial purposes. Namely the removal of nutrients in wastewater, a source of protein for animals, and biorefining into bioethanol and/or biogas. Because of this, it is of interest to examine whether these properties of duckweed can be utilised in any danish industries. The duckweed species of particular interest is Lemna minor, as that is the most abundant one in Denmark. One place where wastewater is present, and thus where duckweed grows, is in the lagoons of fish farms, as stated in section 2.4.1. As lagoons are mandatory for fish farmers to have (Ministry of Environment & Food, 2016), in order to handle the large amounts of nutrients that is a byproduct of the fish production, lagoons, and thus duckweed, can be found in large quantities all around Denmark. The estimate on the number of hectares of lagoons was calculated in the above section 6.1.2. With the estimate of the hectares of lagoons, the wet matter estimate of the growth of Lemna minor was thus calculated to be 11.984.849 kg conservative and 48.281.803 kg liberal.

When harvested, this amount of duckweed is expected to be of interest to industries that produces or uses animal fodder, such as biorefineries and farms, and industries that produces biofuel, such as and biogas plants.

6.2.1 Animal fodder

As stated in section 4.3.2, the addition of both dried or fresh duckweed in the diets of animals from agri- and aquaculture had positive effects on animals, in regards to growth rates, feed conversion ratio, etc.

Animal	Amount
Pigs	16.838.600
Sheep and lambs	71.000
Chickens	104.155.000
Poultry	104.616.300
Total	329.835.900

Table 16: Amount of slaughtered animals in Denmark 2019, (Statistics Denmark, 2020a)

As seen on table 16, the amount of produced animals, in regards to pigs, sheep, lambs, poultry and chickens, reached a total of 329.835.900 animals. This shows that there is a high production of animals, and thus a high amount of fodder needed, in order to raise the animals. With the studied positive effects of adding duckweed to the diets of animals, it can be argued that there is a potential for the utilisation of duckweed in the fodder to animals produced on danish farm, and thus a potential market.

As furthermore stated in section 4.3.2.6 no negative effects was observed with the addition of 20% fresh duckweed in the diets of fish. It can therefore also be argued that there is a potential for the sale of duckweed to the fish farms in Denmark. However, as there was no change in the growth of the fish with the added duckweed, it can be argued that there has to be an incentive for the fish farmers to buy the duckweed. An incentive could be a total reduction of feeding costs for the fish farmer, if the fodder part that the duckweed replaced, is more expensive to purchase than duckweed.

When asked about the possibility of adding duckweed to his fish farm, Peter Holm argued that he saw potential, but required that the duckweed received a pre-treatment in the form of heating, in order to kill any harmless compounds or disease. With this in mind, the sale of freshly harvested duckweed as fodder to animal producing farms is a possibility, but with added steps. The pre-treatment is to be seen as an extra process, thus costing resources to perform, should BioMend be the one to perform it.

According to Adeduntan 2005, in Sońta et al. (2019), the only toxic compound to animals that is found in duckweed, is a compound called oxalic acid. Oxalic acid prevents the absorption of vitamins consumed by both humans and animals, but will upon heating or boiling break down, and thus removed from the plant (Hospital, 2019).

According to Morten Ambye-Jensen, Duckweed has the potential to be utilised together with grass with means of protein extraction. As duckweed doesn't grow in such numbers that it can be harvested every day around the year, it would be difficult to acquire enough biomass to fully use the capacity of a bio-refinery using only duckweed. Thus, the addition of duckweed to grass for protein extraction would be a possibility. Furthermore he would consider the main product made from duckweed to be protein for feed purposes, with the excess fibre product, left after the protein has been extracted, to be used for biogas production.

Should BioMend wish to sell the duckweed directly to fish farmers or farms producing other animals, and thus having to comply with the heating pre-treatment, it would mean that an acquisition of machinery being able to do such heating. Depending on the size of the machine and the amount of duckweed harvested, it could be installed directly on a truck that is transporting the harvested duckweed, making an on-site or even during transport pre-treatment possible. However, should that not be possible due to space limitations on the truck, two other possible scenarios exist. The first one is the installments of the heating machines at the different fish-farms where the duckweed is grown and harvested. The second is the transportation of the duckweed to a single facility, performing the heating pre-treatment. The on-site pre-treatment would mean that the transportation of duckweed is significantly reduced, due to the removal of water, thus saving resources. However, with the current 151 fish farms active as of 2019 (see table 11), an on-site machine installed on every location would be a relative high investment, compared to a facility containing a fewer amount of drying machines.

With the high amount of produced animals in Denmark, it can be argued that a high amount of fodder is needed. The fodder could be partially replaced by duckweed, thus creating a use case for the biomass, with the farmers or fodder manufacturers being possible end users of duckweed. However, if a pre-treatment of the harvested duckweed is required by some farmers, it would mean more processes in general, and thus more resources needed for BioMend.

6.2.2 Bioethanol

As concluded in section 4.3.3, duckweed is a viable plant for the production of bioethanol. Firstly due to its relative high amount of carbohydrates/starch depending on the species. Secondly, due to its readiness for fermentation, with little to no prior treatment required, compared to soybeans and corn, that needs to be grinded down prior to fermentation. It has in 2020 and 2021 been required by danish law to mix a minimum of 7,6% biofuel with conventional fuel (Energistyrelsen, 2021a), such as bioethanol mixed with petrol, bio-diesel mixed with diesel, and biogas mixed with natural gas. Furthermore is bioethanol the primary fuel for bio fireplaces, which is a cleaner solution to a conventional fireplace that uses wood.

This could be reason for a potential market for the utilisation of duckweed as bioethanol, even more so if the law requires a further increase of biofuel mixed with conventional fuel in the upcoming years.

During the interview with Morten Ambye-Jensen (appendix A.2), he was asked whether he saw duckweed with a starch content of 12,15% as a potential candidate for the production of bioethanol. He considered 12,5% to be too low a concentration of carbohydrates for the purpose of making bioethanol, especially in context of the low prices for conventional produced ethanol, from crude oil.

A similar response came from a conversation with Lars Thomsen, who is CEO of Danish Methanol Association. He also claimed that the production of bioethanol from a source with a low content of starch was not feasible compared to the other feedstocks of ethanol and bioethanol, such as crude oil, and the conventionally used corn. Furthermore, Morten stated that they had studied the potential use of bioethanol, but saw it as a low-value product, and thus saw more potential of transforming the biomass into something else with a higher value.

With the stated 4,8 - 14% carbohydrates found in Lemna minor, it can be argued that the utilisation of Lemna minor with the intention of producing bioethanol is not feasible with such a low content, and it can therefore be argued that it is not worth for BioMend to pursue. One could argue that nutrient starvation, with the goal of increasing the starch content of Lemna minor, could be a possibility. However, it has to be seen as an extra process and thus extra resources needed for BioMend. The research into the required extra resources is deemed out of scope for this section, and is thus discussed in section 8.2.

6.2.3 Biogas

Section 4.3.4 concluded that the addition of duckweed in anaerobic digestion increased the overall production of biogas. With the required mix of a minimum of 7,6% biofuel with conventional fuel, such as biogas mixed with natural gas, it can be argued that there is a market for the utilisation of duckweed as a means of producing biogas. In order for the produced biogas to be mixed in with natural gas in the gas grid, it has to be purified first. The purification removes the low-value components of the biogas, such as CO_2, water, and sulfides (United States Environmental Protection Agency, 2021). The now pure bio-methane can then be sold and mixed in with the natural gas, in the gas grid, and be used as vehicle fuel or other energy products.

In order to access the potential customers for the production of biogas, it is of interest to acquire information about the amounts of biogas plants in Denmark.

As of june 2020, there were a total of 186 biogas plants in Denmark (for the list, see appendix B), being separated into five different plant types, namely 51 treatment plants, 7 industrial plants, 28 landfill plants, 36 communal plants, and 64 farm plants, including Research Center Foulum, where Morten Ambye-Jensen is working. The most common feedstock for these plants include livestock manure, wastewater and organic residues and waste products (The Danish Energy Agency, 2021). The use of crops such as corn and beets is possible to use, however, due to the already heavy use of these types of crops, the usage of them makes the production of biogas less climate friendly. Because of this, biogas plants are not allowed to add more than 25% crops in the biogas plant, and from 2018, it was not allowed to use more than 12%, measured as the quantity supplied in tons (The Danish Energy Agency, 2021).

According to The Danish Energy Agency (2021), the actual use of crops in the production of biogas at biogas plants is shown to be significantly lower than the allowed 12%. The low use of crops for biogas production means that the heavily used resource will be more available to be utilised in the production of bioethanol, and for human and/or animal consumption.

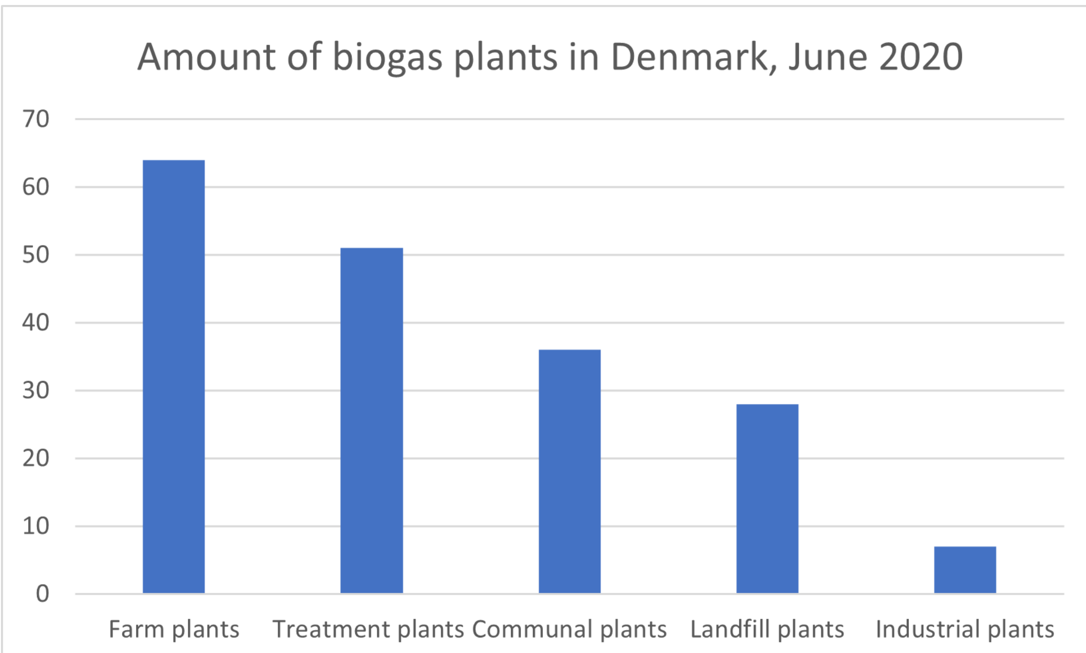

Figure 13: Number of biogas plants in Denmark as of June 2020 (The Danish Energy Agency, 2021)

As seen on figure 13, biogas is mostly produced by farm plants, being in possession of more than 33% of the total amount of biogas plants found in Denmark. As seen in appendix C, the different plants produce a varying amount of biogas, measured in terajoule/year (tj/yr). The production ranges from 1-99, 100-199, 200-399, 400-799 and 800+ tj/yr. The plants producing the highest amount of biogas measured in tj/yr is seen to be the communal and farm plants, which is shown under one collective type of plant in appendix C, namely agricultural plants. Several of the agricultural plants produce more than 800 tj/yr worth of biogas. The lesser plants are the treatment plants, which is assumed to be due to wastewater not containing as many useful components for biogas production, compared to manure.

Furthermore, as seen in appendix D, the biggest production of biogas is in Jutland, as most of the total agricultural plants are found there. The only big biogas plant in Zealand is the industrial plant in Kalundborg, with most of the other plants being treatment plants, which are producing the least amount of biogas due to the low amount of nutrients.

Both farm plants and communal plants mostly use livestock manure from cows, cattle and pigs, as feedstock for the biogas production. As argued in section 4.3.4.1, the addition of duckweed to manure for the production of biogas had a positive effect on the overall production. It can thus be argued that duckweed can be utilised in a danish context, with farm plants and communal plants being a potential end user of the harvested duckweed.

6.2.4 Biorefineries

Lastly, there is the possibility of biorefineries being potential customers for the harvested duckweed. As stated in his interview (A.2), Morten Ambye-Jensen saw potential of the fibre product, left after protein extraction, to be used in the production of biogas. The fibre product would be excess material that is left after most of the water and protein have been pressed out of the duckweed. Both the protein concentrate and fibre product would then be able to be utilised as protein rich animal fodder, and feedstock for biogas production, respectively. By doing this, biorefineries are able to achieve two use cases of the duckweed, instead of only one. Doing this not only eliminates waste from an economical and ecological perspective, but also serves to utilise all the resources that the plant has to offer. In the case of only using the duckweed as animal fodder, with the required heating pre-treatment, a lot of the protein and carbohydrates might be lost together with the water evaporating, resulting in waste. The same would apply in the case of the raw duckweed being used for biogas production, with a lot of unused protein being wasted.

When asked about the economical evaluation of the use of biomass for the biorefining, Morten stated that their calculations were based on a number of assumptions:

1. The biomass that they would use (in his case grass) is produced and delivered at a price of 1DKK/kg freshly harvested grass
2. It is treated at a biorefinery plant
3. The excess bio-material from the pressing is used to produce biogas
4. The protein concentrate (roughly 50% protein) is sold as organic feed, which will substitute organic soy-protein, which has a higher market price of about 6DKK/kg.

With these assumptions, Morten stated a possibility for profit from grass as an input at a bio refinery.

Ambye-Jensen et al. (2017) describes the biorefining of grass with a dry matter content of 18% and a protein content of 20% of the dry matter. This biorefining yields a fibre product with a dry matter content of 30% and a protein content of 17% of the dry matter. The starch content of the fibre product is not mentioned. Furthermore, the separation of the juice product yields a protein concentrate with a dry matter content of 28%, and a protein content of 47% of the dry matter, with the residual juice containing a dry matter content of 8% and a protein content of 4% of the dry matter.

To compare, Wiltink (2017) achieved the following results, from the biorefining of an unmentioned duckweed species into a fiber product, and a juice product:

Duckweed	*g/kg*		*g/kg*
Total weight	1000		
Liquid	945,6		
Dry matter	54,3		
		Crude protein	24,7
		Carbohydrates	12,2

Table 17: Composition of fresh duckweed biomass (Wiltink, 2017)

Fiber product	g/kg	g/kg
Liquid	891	
Dry matter	109	
	Crude protein	25
	Carbohydrates	40,7

Table 18: Composition of fiber product (Wiltink, 2017)

Juice product	g/kg	g/kg
Liquid	907	
Dry matter	93	
	Crude protein	69
	Carbohydrates	7,8

Table 19: Composition of juice product (Wiltink, 2017)

Looking at table 17, 18 and 19, it can be derived that the fresh duckweed biomass has a dry matter content of 5,4%, and of that dry matter, 45% is protein, and 22% is carbohydrates.

The fiber product contains 10,9% dry matter, and of that dry matter, 22% of it is protein, and 36% of it is carbohydrates.

The juice product contains 9,3% dry matter, and of that dry matter, 74% is protein, and 8,3% is carbohydrates.

The duckweed used in the biorefining has a protein content of 45% dry matter, which is substantially higher than the protein content of Lenma minor, which is discussed to have a protein content of around 20% in section 4.3.2. Because of this, it can be argued that the protein concentration of both the fiber product and the juice product of biorefined Lemna minor, would be lower than of that presented by Wiltink (2017). However, the amount of carbohydrates seems to be approximate to that of Lemna minor, and it can thus be argued that the concentration of carbohydrates in the fiber product and juice product of biorefined Lemna minor, would be similar to that presented by Wiltink (2017).

The difference between Lemna minor and the grass mentioned in the example from Ambye-Jensen et al. (2017) is the dry matter content. As Lemna minor contains 5% dry matter as described in section 2.4.1, versus the 18% dry matter of the grass, it can be argued that the fibre product and the protein concentrate from the biorefined duckweed would contain more water. The larger amount of water can be mitigated by pressing the fiber product and the juice product more than once, in order to remove more excess water.

With the protein content of biorefined Lemna minor being similar to that of grass, and with Morten Ambye-Jensen showing his interests for the use of Lemna minor, it can be argued that biorefineries are a potential customer for the harvested Lemna minor. As Morten stated, the cost of the grass they use for the biorefining is bought at a price of 1 DKK/kg freshly harvested grass A.2. As the protein content of grass and Lemna minor is very similar, it can be argued that freshly harvested duckweed can be sold to Morten as a similar price. However, as Lemna minor contains around 13% more water than grass, it will ultimately require more biorefined duckweed to achieve the same amount of fiber product and protein concentrate, compared to grass. With that said, duckweed would require little to none mechanical grinding, which is a required process for all biomass before being pressed. The reason for the little required grinding is due to the water content of duckweed being so high, together with its small size (Cheng and Stomp 2009, in (Wiltink, 2017). Grass must be severely grinded before pressing since it is too big, firm, rigid, and has more dry matter. The grinding process, also known as fiberizing, meshes up the grass and opens up the cells, and as a result, a major part of the proteins is made accessible for pressing (Wiltink, 2017). Fiberizing is a process that requires a high amount of energy (O'keffe, Schulte, Sanders and Struik 2011, in (Wiltink, 2017), and elimination or severe reduction of that process would save large amounts of energy, and thus time and money. Because of this it can again be argued that Lemna minor could be sold at a similar price of grass, namely 1 DKK/kg freshly harvested duckweed.

Furthermore, the interview with Robert Mouritsen found in appendix A.3, who works at Biorefine Denmark, also showed interest in the use of Lemna minor for biorefining, with the goal of producing protein rich animal fodder and biogas. However, compared to Morten Ambye-Jensen, who works at a biorefinery that functions as a research facility, Robert works at a biorefinery that is a private company. Because of that, his price for the buying of duckweed was at 1 DKK/kg dried duckweed. As 5% of harvested duckweed is dry matter, the price that BioMend would receive for Lemna minor sold to Biorefine Denmark, would be based on dry matter, instead of fresh matter.

6.3 Value chain of duckweed

The value chain of BioMend will in this section be mapped from two perspectives. The overall processes needed to utilise the Duckweed for a specific use-case, and the economical estimations of costs and profit generating elements of the value chain.

6.3.1 Choosing the right use case

Based on section 6.2 it can be argued that there are several use cases for harvested Lemna minor. The use cases are the production of either animal fodder, biogas, or both via biorefinering. As biorefineries have shown interest in the acquisition of duckweed, either freshly harvested or dried, it can be argued that there are customers on the Danish market for Lemna minor. As prices have been acquired for the sale of Lemna minor to both Foulum biorefinery and Biorefine Denmark, it would be of most interest to further investigate the scenario that is the sale of duckweed to those two plants.

When contacted, Biogas Denmark, who is an interest group, responded that they were not able to give any information regarding the purchase or sales prices of feedstocks for biogas production, due to competition authorities.

In another attempt to acquire information about the sales or purchase prices of biomass for biogas production, Jacob Lindhardt Palm was contacted, who is a biomass purchaser for the biogas company Nature Energy. He too was very reluctant about giving pricing information. It was assumed that this too was due to competition reasons. According to Morten Ambye-Jensen the biogas industry has a price structure of three pricing tiers. In the first tier, customers pay for the delivery of biomass to the facility. In the second tier, bioproducts are delivered at neither cost or payment. Third tier is for high value products, where the biogas facilities pay for the products delivered. The third tier is often biomass delivered from the medical industry.

The prices for the sale of duckweed to biorefineries was obtained from Morten Ambye Jensen and Robert Mouritsen. As the pricing of the duckweed is based on fresh matter in the case of sale to Foulum Biorefinery, and dry matter in the case of sale to Biorefine Denmark, the difference in revenue from these two will be quite substantial.

The calculated total growth of Lemna minor on the combined fish farms, which was calculated in section 6.1.3, was separated into a conservative and liberal production, respectively. The conservative yearly production was estimated to be 11.543.355 kg duckweed, while the liberal yearly production was estimated to be 46.502.218 kg duckweed.

Sale of duckweed to Foulum biorefinery	Conservative	Liberal
Price/kg fresh matter	1 DKK	1 DKK
Amount of duckweed in fresh matter (kg)	11.984.849	48.281.803
Revenue (DKK)	11.984.849	48.281.803

Table 20: Conservative and liberal revenue generated from the sale of duckweed to Foulum biorefinery

As seen on table 20, the yearly revenue from the sale of duckweed to Foulum biorefinery would be between 11.984.849 DKK and 48.281.803 DKK.

When looking at the revenue generated from the sale of duckweed to Biorefine Denmark, it is reduced quite a bit. This is due to the fact that the value of 1 kg of duckweed in reduced by 95%, as they pay for kg dry matter, instead of kg fresh matter. The yearly amount of harvested duckweed would thus be 599.242 kg dry matter conservative, and 2.414.090 kg dry matter liberal.

Sale of duckweed to Biorefine Denmark	Conservative	Liberal
Price/kg dry matter	1 DKK	1 DKK
Amount of duckweed in fresh matter (kg)	599.242	2.414.090
Revenue (DKK)	599.242	2.414.090

Table 21: Conservative and liberal revenue generated from the sale of duckweed to Biorefine Denmark

As seen on table 21, the revenue generated from the sale of duckweed to Biorefine Denmark is substantially lower compared to the sale to Foulum diorefinery. Because of this, it is assumed that BioMend would prefer the sale of duckweed to Foulum biorefinery, as that would generate a higher revenue.

However, since Foulum biorefinery is a research facility, one could argue that they might one day not be in need of any more bio matter, such as duckweed, should they finish their research, or should their funds run out. It is therefore more realistic to see the sale of duckweed to Biorefine Denmark, as their biorefinery works as a business, with expectations to continue operations indefinitely.

As the sale of duckweed to both biorefineries have proven to be realistic, with expected revenue gained from the sale of duckweed to both of them, the analysis will continue with that assumption. Furthermore, during his interview, Morten Ambye-Jensen mentioned the biorefinery named Ausumgaard as being a potential customer for BioMend, they will be taken into consideration as well. The value chain of duckweed will therefore be analysed with the processing of duckweed to those plants, thus resulting in different scenarios for the transport of harvested duckweed from the many fish farms located in Denmark.

6.3.2 The harvest of duckweed

The first challenge in the value chain that needs to be solved is the harvest of the duckweed from the lagoon. There are a number of requirements to this process that will define the best solution.

1. Efficient harvest of the duckweed
2. Minimum damage to the plant
3. Accessibility and flexibility of machinery
4. Economical feasible solution

The Process of harvest needs to be efficient both in terms of the process time and in terms of the ability to pick up the duckweed from the water surface. In order for the duckweed to be utilised for further processing in a bio-refinery, the plant structure must not be destroyed. Destruction of the plant membrane can lead to reduced protein content in the biomass as explained by Robert Mouritsen in his interview (appendix A.3). The method used for harvesting needs to be flexible enough to manoeuvre around at the fish farm. Depending on the layout on the specific fish farm will there be more or less space around the fish farm. For that reason will the mechanism for harvest needed to be flexible enough to reach potential narrow areas of the lagoon. Lastly will the cost of acquisition of machinery, as well as cost operation be taken into account.

The Harvest mechanism will consist of two main components, a motor and a water separator. The motor will ensure transportation from the lagoon to the container. The separator will remove the excess water that is sucked up from the lagoon together with the duckweed. In the following section, two potential approaches of these components will be evaluated.

6.3.2.1 Pump system

The first type of pump to be investigated is the centrifugal pump. This type of pump has a high efficiency and can be driven by a petrol engine. This engine can be moved easily, thus making it flexible in terms of location. It is an important feature that the pump does not rely on power from the electrical grid, as there will not be access to electrical power at all locations on fish farms. The structure of duckweed allows for undisputed flow through the pump. The Danish technological institute has previously used this type of pump for duckweed harvest (Ja Aktuelt, 2019). This method was confirmed in a phone conversation with the project owner, Bodil Pallesen. The centrifugal pump does not have elements that create any significant amount of damage to the plant.

The price of this type of pump is typically around 10.000DKK to 15.000DKK depending on the size. A water pump from Honda (Holm, 2021) has a nominal capacity of 1.210 $l/min.$ and are able to pump water containing earth and small stones up to a size of 26mm in diameter. The maximum pump height for the pump to lift the water is above 20m, which will be more than sufficient for this use case. This specific pump has a cost of 13.625DKK.

The second option for a pump is an idea by Peter Holm. He explains that fish farmers will have an dredging tool[16] available at the fish farm. This is a tool, that is usually used for maintenance of the lagoon. The dredging tool is attached to a tractor. The dredging tool can handle larger amounts of debris than the centrifugal pump. In regards to capacity, this pump is comparable to a centrifugal pump. The tractor driving the pump will be able to drive along the lagoon and thereby cover the complete area. As this tool is already available at the fish farms, the initial cost of investment for a pump be will eliminated. The disadvantage of using the dreading tool is that it might be used for wide variety of tasks. This have the potential

[16] Tool for removal of residue of all kinds in combination with water. The tool uses as rotating thread for transport of materials

to compromise the quality of the duckweed. A situation where this could be an issue is if the dreading tool have been used for moving water containing mud. Lastly is the availability of this tool not guaranteed, as the fish farmer him self might be using it at the time of harvest.

6.3.2.2 Water separation system

The first method for separating the water and duckweed investigated is a product called Geotube. A Geotube is a heavy duty fabric that can let water though but not the duckweed. This method have been used in the previous mentioned project at The Danish technological institute (Ja Aktuelt, 2019). The pressure put on the plant under water separation can differ depending on the water pressure created by the pump. Under too high pressure will there be a risk of pressing out the protein in the plant. The Geotube itself takes up a large amount of space and require furthermore additional handling of the harvested duckweed once it have been separated from the water.

The price of Geotube is about 20DKK/m (Indiamart, 2021). In the context of the of this use case will about 15 meters of Geotube be required. That means that a Geotube is very price efficient.

The second type of water separator is called a Rotative fat drainer from a company called Haarslev Processing Technology Technology (2021). This machine is designed to have an input of liquid and solid material. All liquid will be removed through a fine perforated rotating cylinder. Through this method, the water separation will be gentle for the plant. The speed of the water separation can be adjusted to the input rate of the pump. Even though this machine is made for separating liquid fat from food, it has been confirmed by a product engineer at Haarslev Processing Technology, that it will work for separating water from duckweed. The benefit of using a machine that is approved for processing food for human consumption, is that the risk of contamination of the product is reduced to a minimum. Secondly will the pure duckweed be ready for transport afterwards. In order to get the price of the Fat Drainer, Haarslev Processing Technology was contacted directly. The price of the base model is 156.000DKK.

6.3.2.3 The final harvest solution

The solution chosen for harvest in the further analysis will be outlined in this section. For the pump system, a centrifugal pump will be used. This type of pump provides the lowest risk of contamination of the product, as well as the flexibility of transportation from one fish farm to the next, because this owned by BioMend. For the separation of water and duckweed, the Rotative fat drainer is used. The key feature provided by this machine is the ability to separate the water without the risk of damaging the structure of the duckweed. A necessary element of the harvest mechanism is a hose between the lagoon and the pump. The pump is approved for food processing to minimise the chance for contamination. The price per meter is about $130 DKK/m$. It is estimated that about 100 meters is needed for harvest in the lagoon area.

The process of harvest requires personal to function. With the suggested configuration, is it assumed that it takes two people to operate the harvest machinery. The labour cost is set to 150DKK/h based on the regular pay for labour in the fish farm industry (K. K. Hansen, 2021). The harvest capacity estimation is based on the nominal capacity of the pump at 1.210 l/min. As the duckweed is found in the top layer of the water, a high percentage of the sucked up material will be water. It is estimated that only about 30% is actually duckweed. In total, the labour cost for the harvest of one tonne will be:

$$\frac{1.000\ kg}{1.210\ kg/min. * 30\%} * \frac{2 * 150\ DKK/hour}{60\ min/hour} = 13,77\ DKK/tonne \quad (4)$$

The calculated running costs is based on the harvest of 18.000kg as this is the maximum capacity of a container. This means that the cost of harvest for a full container is 247,93 DKK.

For context is the maximum harvest of duckweed pr. hour calculated in equation 5:

$$Maximum\ harvest\ rate\ = \frac{1.000\ kg}{1.210\ kg/min. * 30\%} = 21.780\ kg/hour \tag{5}$$

The maximum labour cost from a conservative and liberal perspective can be calculated based on the above calculated harvest rate, equation 5 and table 14.

Market potential	Total labour time (hour)	Total labour cost (DKK/year)
Conservative	550	165.078
Liberal	2.217	665.028

Table 22: Yearly cost of labour

The total fixed cost of the equipment for the harvest mechanism is about 183.000 DKK as shown in table 23.

Fixed cost	Cost (DKK)
Water separation	156.000
Pump	13.625
Hose	13.000
Total	182.625

Table 23: Fixed cost of the harvest mechanism

6.3.3 Transportation of duckweed

As stated in section 6.3.1, the transportation of duckweed will be based on the three plants, Foulum biorefinery, Biorefine Denmark, and Ausumgaard being recipients of the harvested duckweed. As the biorefineries are placed in different parts of Denmark, more specifically Jutland, the distance needed to travel for the truck delivering the duckweed will vary, and thus will the transportation price assumed to vary as well. In order to estimate the distance that the trucks need to travel from harvest site to biorefinery, and later estimate the price for that travel, an assessment of the placement of the fish farms together with the placement of the biorefineries will be made. The duckweed will need to be transported directly to the biorefinery to reduce chance of a decomposing processes to start as stated by Robert Mouritsen in appendix A.3.

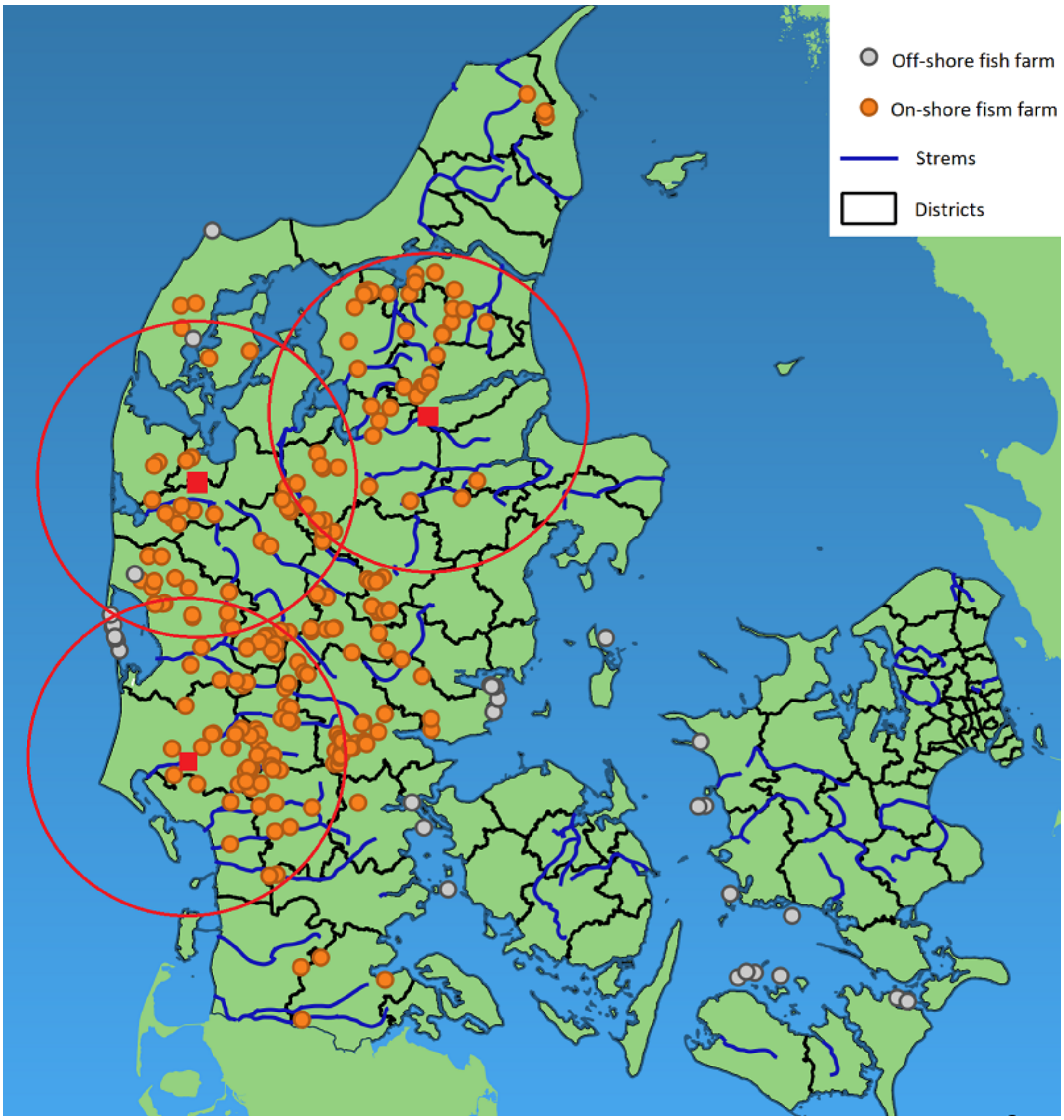

Figure 14: Location of fish farms and three biorefineries in Denmark (Akvatultur, 2021)

Figure 14 shows the location of fish farms and Foulum biorefinery (top right), Biorefine Denmark (bottom left) and Ausumgaard (top left), with the orange dots being fish farms, and the red squares being the biorefineries. The red circles is used to help visualise distance, with the diameter of each circle being 100km, thus having a radius of 50 km. The circle is placed with the biorefinery in the middle, in order to showcase what fish farms are at an approximate distance of 50 km. The majority of the fish farms are placed within the respective circles, with some fish farms being close to 100 km away from a biorefinery.

With approximately 151 fish farms, it is of interest to calculate the cost of transportation of the harvested duckweed from the fish farms to the biorefineries.

In order to do this, the transportation company Per Nielsen A/S was contacted, to gain insight of the costs of transport of the biomass.

From the the conversation, the costs of transportation was based on two fixed prices:

1. The rental of a water sealed container, priced at 100 DKK
2. The price of transport of the duckweed, fixed priced at 1.200 DKK

The price of 1.200 DKK for the transport of duckweed is fixed, and is paid for each individual collection from fish farm to biorefinery. Furthermore, the water sealed container is able to contain a maximum of 18 tonnes of biomass, as stated in 6.3.2.3

This creates three scenarios of costs: a case specific transport cost, namely that of transporting one full truck of duckweed to a biorefinery, as well as a yearly conservative transport cost and a yearly liberal transport cost. Here, the conservative and liberal transportation costs are based on the amount of times a truck has to travel with 18 tonnes of biomass, in relation to the conservative and liberal yearly growth of duckweed, that is 11.984.849 kg and 48.281.803 kg respectively.

Process	Cost (DKK)
Rent of water sealed container	100
Transport of 18 tonnes of duckweed	1.200
Total transport costs	1.300

Table 24: Case specific cost of transport of duckweed from fish farm to biorefinery

For the transport of the conservative yearly produced duckweed at 11.984.849 kg, or 11.985 tonnes, a truck being able to transport 18 tonnes each time, would result in 666 total transportations.

Proces	Conservative	Liberal
Rent of water sealed container	100	100
Transport of 18 tonnes of duckweed	1.200	1.200
Yearly amount of conservative transport	666	2.682
Total yearly conservative transport costs (DKK)	865.800	3.486.600

Table 25: Conservative and liberal yearly cost of transport of duckweed from fish farm to biorefinery

Thus, the total yearly transportation costs would be 865.800 DKK or 3.486.600 DKK, depending on the conservative growth rate or liberal growth rate.

6.4 The Business Case

To give an overview of this solution, the framework "The Business Case for Environmental Sustainability" (Wills, 2009) has been used. This framework have been chosen to give a broader perspective of environmental, social and economical aspects. Schaltegger et al. (2012) created a comparison of different approaches to the business case. This comparison shows how a business is able to increase the environmental image and economical benefits, by including the social, environmental and economical aspects. This is done by including a holistic perspective of beneficial and disadvantageous elements of the proposed business idea. Karlsson et al. (2016) defines the three aspects of a "green" business case as: "the environment (the planet, all life, and all associated processes), society (people as individuals and groups), and the economy (revenues, costs, and profit)".

6.4.1 Product offering

The presented value proposition is split into two areas. (1) Nutrient emission management for fish farmer and (2) supplier of protein rich biomass for biorefineries. The key activities for the product offering, is to harvest duckweed biomass at fish farms and transport the biomass to biorefineries. This value proposition is an integration of circular supply chain between three actors. The goal of the circular supply chain is to minimise the use of imported soy protein for use in the animal fodder production, while decreasing the overall nutrient emission. In figure 15, a visual representation of the newly developed circular supply chain can be seen. The circular supply chain begins at the fish farm where the biomass is produced. The biomass is delivered to biorefineries, that produce concentrated protein for the fodder production facilities. The output from the fodder production can be delivered to a number of farmers, with some of it delivered back to the fish farmers.

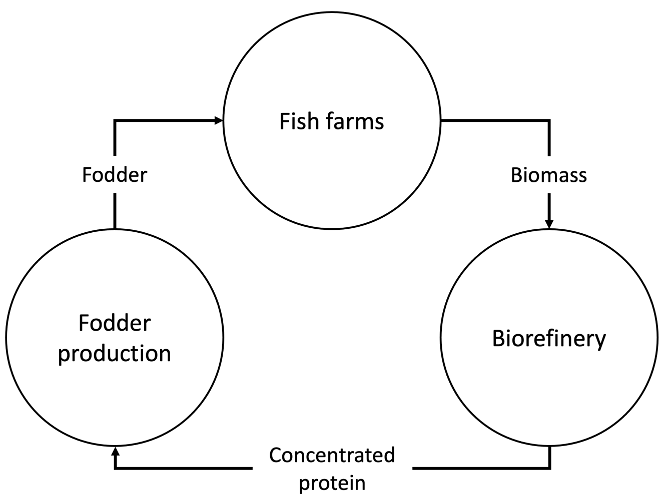

Figure 15: Contribution to a Circular supply chain

6.4.2 Economical evaluation

The first step of the framework for a green business case looks at the direct economical consequences that comes as a product of BioMends actions. This can be seen from several perspectives, with the first being the case of BioMend itself, and the second one being the case of those affected by BioMends actions, such as fish farms and industries like biorefineries, that can utilise duckweed.

Regarding the case of BioMend, in order to assess what costs that are associated with the processing of duckweed, compared to the earnings as a result of harvest and sale of duckweed, a break-even analysis will de conducted, in order to clarify the different costs and earnings that the harvesting, transport and sale of duckweed brings.

A break-even analysis helps showcase what decisions BioMend should make based on the impact that the costs have on the revenue, and thus the earnings that can be made. In this case, the costs will be the harvesting and transport of duckweed, where the benefits will be the revenue that is generated from the sale of duckweed, and the payment from fish farmers from the removal of nutrients in the wastewater lagoons. However, the benefit of the solution that BioMend brings, should not only be seen in regards to economical earnings, but also the environmental and socioeconomic benefits. This is described in section 6.4.3

In the previous sections, the different economical costs and earnings that is associated with the harvest, transport and sale of duckweed, has been calculated and presented.

In regards to costs that is associated with the harvest and transport of duckweed, the costs for harvest were covered in section 6.3.2.1 and 6.3.2.3, and the cost of transportation was covered in section 6.3.3. In regards to earnings, they can be split up into two categories: The payment received from fish farmers for the removal of nitrogen (N) and phosphorus (P), and the payment received from the biorefineries for the sale of duckweed.

The payment received from the biorefineries was calculated in section 6.3.1

To calculate the revenue received from the removal of N and P, one needs to look at three aspects. These include the rate at which Lemna minor removes N and P from the water, the yearly growth of Lemna minor, and the price that fish farms would pay for each kg N and P removed.

With a content of 8,74% nitrogen (N) and 0,83% phosphorus (P) respectively in dry matter, as shown in table 3, the yearly amount of N and P that is removed with the growth of Lemna minor can be calculated. As calculated in table 21, the total conservative and liberal amount of Lemna minor that can be produced in dry matter is 599.242 kg and and 2.414.090 kg respectively. The price that fish farmers is willing to pay for the removal of N and P is 10 DKK/kg nitrogen and 50 DKK/kg phosphorus respectively, as stated in section 6.1.4. with these numbers, it is possible to calculate the yearly conservative and liberal revenue generated from the removal of nitrogen and phosphorus:

Proces	Conservative	Liberal
Nitrogen		
Nitrogen removed (%)	8,74	8,74
Annual duckweed produced in dry matter (*kg*)	599.242	2.414.090
Price for 1 kg nitrogen removed (DKK)	10	10
Revenue from removed N (DKK)	**523.738**	**2.109.915**
Phosphorus		
Phosphorus removed (%)	0,83	0,83
Annual duckweed produced in dry matter (*kg*)	599.242	2.414.090
Price for 1 kg phosphorus removed (DKK)	50	50
Revenue from removed P (DKK)	**248.685**	**1.001.847**
Total marked revenue potential from removed N and P (DKK)	**772.423**	**3.111.762**

Table 26: Total potential revenue gained from removal of nitrogen and phosphorus

As stated in 6.1.1, the government regulates the total nutrient emissions from fish farms, and thus requires fish farmers to dispose or remove the nitrogen and phosphorus from the lagoons. As duckweed grows by absorbing both of these minerals, the removal of duckweed from the lagoon can be seen as being in compliance of the removal of nitrogen and phosphorus as mandated by the government.

In sum, the total earnings, that is derived from the revenue and costs associated with the harvest, transport and sale of duckweed can be calculated. The cost of harvest of duckweed was calculated in table 22, the cost of transport was calculated in table 25, the revenue from the removal of nitrogen and phosphorus was calculated in the above table 26, and the revenue from the sale of duckweed was calculated in table 20 and 21.

The total potential earnings calculated for conservative and liberal scenarios, with the sale of duckweed to either Foulum biorefinery or Biorefine Denmark, respectively in table 27.

Processes (DKK/y)	Foulum biorefinery		Biorefine Denmark	
	Conservative	Liberal	Conservative	Liberal
Cost of duckweed harvest	-165.078	-665.028	-165.078	-665.028
Cost of duckweed transport	-865.800	-3.486.600	-865.800	-3.486.600
Revenue from removed N and P	772.423	3.111.762	772.423	3.111.762
Revenue from sale of duckweed	11.984.849	48.281.803	599.242	2.414.090
Potential profit	**11.726.394**	**47.241.937**	**340.787**	**1.374.224**

Table 27: Total market potential for the harvest, transport and sale of duckweed to biorefineries

As it can be seen, there is by far the highest earnings from the sale of duckweed to Foulum biorefinery. However, as previously discussed, Foulum biorefinery is a research facility, which could at any time end its research, and thus its need for duckweed. Biorefine Denmark on the other hand, is a commercial biorefinery, and is thus more likely to continue operations in the future.

Because of this, in context of future scenarios is it deemed more realistic to focus solely on commercial biorefineries. With this in mind, the break-even calculation will be made in regards to the sale of duckweed to Biorefine Denmark.

The formula for calculating the break even point is:

$$Break\ even\ point\ = \frac{Fixed\ costs}{sales\ price\ per\ unit - variable\ costs\ per\ unit} \tag{6}$$

The data for the break even point, that is the fixed and variable costs sales price per unit, will be based on a unit of 1 kg duckweed.

The variable price of harvest of 1 kg of duckweed is calculated by taking the harvest price of 1 tonne of duckweed from equation 4, and dividing it by 1000 to get it for 1 kg duckweed:

$$\frac{13,77DKK}{1000} = 0,01377DKK/kg \tag{7}$$

The fixed price of transport of 1kg duckweed is the same as the price of transport of 18 tonnes of duckweed, namely 1.300 DKK.

The revenue gained from the removal of nitrogen and phosphorus in 1 kg duckweed is calculated to be:

$$(1kg * 5\% * 8,74\% * 10\ DKK) + (1\ kg * 5\% * 0,83\% * 50\ DKK) = 0,064\ DKK \tag{8}$$

Here, the 5% is the dry matter content of Lemna minor, the 8,74% and 0,83% being the nitrogen and phosphorus concentration of Lemna minor respectively, as shown in table 3, and the 10DKK and 50DKK being the sales price of 1kg removed nitrogen and phosphorus, respectively, as described in section 6.1.4.

The revenue gained from the sale of 1kg of duckweed to Biorefine Denmark is calculated to be:

$$1\ kg * 0,05\ DKK = 0,05 DKK/kg \tag{9}$$

Thus, the calculation of the break-even point for the harvest and sale of duckweed is calculated to be:

$$\frac{1.300\ DKK}{(0,064\ DKK/kg + 0,05\ DKK/kg) - (0,01377\ DKK/kg)} = 12.912,72\ kg \tag{10}$$

The break-even point can thus be seen to be at the harvest and sale of 12.912,75 kg duckweed. Amounts lower than that will result in negative earnings, and amounts higher than that would result in profit.

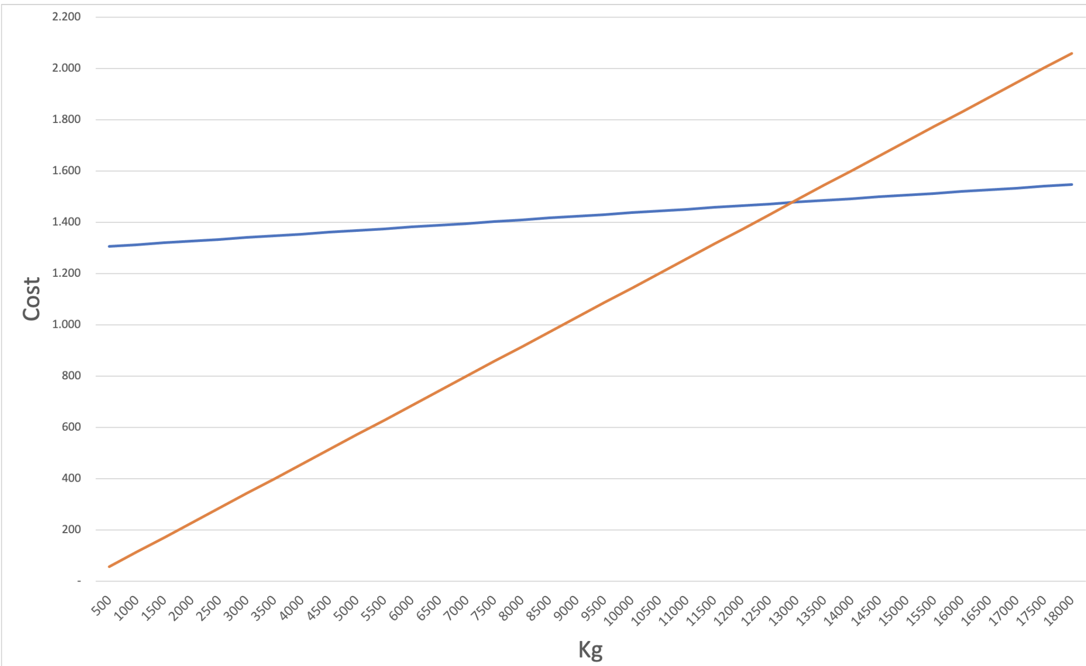

Figure 16: Break-even point of harvest and sale of duckweed

As a single truck has a capacity of 18.000 kg duckweed, it can thus be concluded that a fully loaded truck would result in a positive earning. The maximum potential earning is derived from the revenue and costs associated with the harvest, transport and sale of 18.000 kg duckweed, and is calculated to be to be 512 DKK.

6.4.3 Socioeconomic evaluation

Besides the economical earnings that the utilisation of duckweed would bring BioMend, several other entities are economically affected by the actions of BioMend, with the harvest and sale of duckweed. In the context of fish farmers, the harvest of duckweed from the wastewater lagoons results in an overall decrease of nitrogen and phosphorus. As stated in table 9, the use of 1 tonne of fodder releases 56 kg nitrogen and 4,9 kg phosphorus. 56 kg of nitrogen is equivalent to 12.815 kg duckweed. There is a limit on how much nitrogen and phosphorus a fish farmer is allowed to emit, as seen on table 10. Better nutrient emission management will allow fish farmers on Emission based environmental approval to produce more fish. That means that, if 4,9kg phosphorus and 56kg nitrogen is removed from the wastewater, the fish farmer to then use 1 more tonne of fodder. The feed of 1 tonne fish fodder, results in the production of 1.1 tonne of fish, which generate a profit of 12 DKK/kg to the fish farmer (K. K. Hansen, 2021).

Process	Unit
Produced fish (kg)	1.100
Price of fish (DKK/kg)	12
Cost of getting 56kg nitrogen and 4,9kg phosphorus removed (DKK)	-805
Total potential profit (DKK)	12.395

Table 28: Earnings from fish farmers associated with the removal of duckweed

Thus, the production of 1.1 tonne of extra fish would result in an additional earning of 12.395 DKK for the fish farmer. Some of these money would end up as taxes, and some of the money would be used for the payment of removal of more phosphorus and nitrogen, resulting in more produced fish, etc. As such, fish farmers is seen as one of the beneficiaries of the removal and utilisation of duckweed.

Other entities benefiting economically are the biorefineries selling the protein concentrate, and the customers of the biorefineries buying the protein concentrate. As stated by Morten Ambye-Jensen in his interview in appendix A.2, the sale of protein concentrate made from duckweed, would substitute soy protein, that has a higher market price of about 6 DKK/kg. As it sells at a higher price, it can then also be assumed to be purchased at a higher price compared to duckweed. Should that be the case, the purchase and sale of duckweed, at a lower price respectively, would result in saved resources.

Furthermore, the use of duckweed to produce protein concentrate would remove or drastically reduce the grinding process that is a step that comes before the pressing of biomass into concentrate, as described in section 6.2.4. As it is a energy and time intensive process, the removal of that would also result in saved resources.

As stated in section 4.3, soybean is a crop that is already heavily used in other industries, such as human consumption and the production of biofuel. The substitution of soybean for duckweed would result in an overall decrease of soy use, thus giving more capacity for the utilisation of the crop for biofuel and human feed products.

With the increased substitution of duckweed in animal fodder and biogas production, a decrease of other feedstocks is expected. One of the feedstocks that should decrease is soybean, which is imported in relatively large quantities from all around the globe, to Denmark.

t/year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Argentina	1.048.956	1.160.097	1.212.861	829.949	493.343	576.980	832.568	579.422	541.591	496.258
Brazil	127.463	283.119	208.840	222.977	241.922	191.681	117.552	63.609	185.268	179.530
Canada	-	-	21.501	18.444	23.791	19.440	-	15.151	20.922	21.198
China	-	2.734	7.848	13.613	18.280	20.358	22.253	35.367	55.738	67.793
Netherlands	98.133	55.032	92.170	73.670	88.869	96.490	84.592	42.971	85.763	52.598
Paraguay	3.771	2.512	-	-	13.000	54.499	41.116	120.550	45.448	63.651
Germany	91.498	47.453	82.934	128.586	340.734	356.447	457.675	666.575	544.972	629.513
USA	-	32.823	45.139	119.137	232.768	244.817	170.881	39.900	4	36.000
Rest of the world	68.347	18.270	33.771	21.206	12.232	30.582	22.796	63.083	123.858	161.117
Total	1.438.168	1.602.040	1.705.064	1.427.582	1.464.942	1.591.294	1.749.433	1.626.628	1.603.564	1.707.658

Table 29: Danish import of soybean in tonnes pr. year (IFRO, 2019)

As seen on table 29, import of soybean has been fluctuating at about 1.5 million tonnes each year, from 2009 to 2018. Argentina was the biggest supplier of soybean to Denmark from around 2009 to 2015. After this, Germany became the biggest supplier of soybean to Denmark. It should however be noted that some of the soybean supplied from Germany and the Netherlands originally comes from Argentina and Brazil (IFRO, 2019).

Import of soybean in such huge numbers are bound to have conditions climate wise, with such big travel distances from Brazil and Argentina to Denmark. According to IFRO (2020), danish import of soybean and palm oil emit close to 7 million tonnes of CO_2 early. To compare, the danish agriculture emits 12 million tonnes of CO_2 early (IFRO, 2020).

92% of imported soy (Callesen et al., 2020) is used in the feed diets of farm animals. The substitution of soybean for duckweed in animal diets and biofuel production would result in a decrease of used soybean, thus an assumed decrease in early imported soybean which would result in less CO2 emitted.

6.4.4 Increased customer loyalty and attraction

The customer loyalty and attraction for this solution can be viewed from two perspectives. The solution targets to create value for both fish farmers and companies producing concentrated protein for fodder. The customer loyalty and attraction is important for the solution as it relies on the access to the fish farmers lagoon areas in order for the access to duckweed. Furthermore, BioMend is in a vulnerable phase as a startup with no existing customer base. In order for BioMend to achieve loyalty and attraction from potential customers, the startup needs to convey information regarding the value creation that can be delivered to the customer.

6.4.4.1 Fish farmers

Fish farmers have since the 1980's had a bad reputation because of high nutrient emission. The phosphorus and nitrogen emission was about 3 and 2,5 times higher respectively than today (Amt et al., 2006). Despite a number of successful efforts to reduce nutrient emission, the industry still has a higher emission than the total governmental target, as mentioned in section 6.1.4.

The solution proposed to BioMend will furthermore allow the fish farmers to increase production as removal of nutrients from the excess water allow for a larger fish production. The industry of fish farms has been growing in both yearly production and total value, 33,5% and 45,3% from 2009 to 2019, respectively. As the industry is growing, the need for better nutrient emission management will increase. That means that the industry of fish farmers have a clear incentive to support initiatives that provide an economical feasible tool for nutrient emission management.

From an public image perspective, is the solution also attractive for the industry of fish farmers. At the moment is this industry integrated in two value chains. First and foremost does this industry deliver fish to consumers. The second is fertilizer for agriculture, that comes from the biological solid waste from the fish production. The value proposition form BioMend allow for integration of a third value chain, as contributor of biomass in a circular supply chain of protein.

The potential value creation for fish farmers needs to be communicated to the industry. A key actor, in the work to distribute knowledge of the solution, is the chairman of Danish freshwater aquaculture, Peter Holm. He should be viewed as a key stakeholder in further engagement with the fish farm industry. The goal for BioMend should be to increase awareness of the value proposition and thereby increase attraction from this costumer segment.

6.4.4.2 Biorefineries

Biorefineries is the most feasible customer for raw duckweed, as shown in section 6.3.1. This is a newly started production method, that saw it's first industrial production facility in September 2020 and the second in April 2021. Before this, biorefineries was only seen at a research facility at AU Foulum.

In regards to future growth, the industry of biorefineries is searching for new potential protein value chains from green biomass. At the moment, Foulum research facility has a production capacity of 16.500t biomass per year (see appendix A.3). Robert Mouritsen explains, in appendix A.3, that Biorefine Denmark have a total capacity of 50.000t dry matter biomass per year. Biorefine Denmark is looking for new biomass, that can support the up scaling of the production. Their aim is to double the production capacity in the next few years to come. BioMend has a unique opportunity to be integrated in a newly started industry of protein production in Denmark. It will be of great interest for BioMend to ensure a close collaboration with AU Foulum, Biorefine Denmark and Ausumgaard biorefinery.

6.4.5 Increased employee attraction and retention

As BioMend is a startup with no employees at the moment, employee attraction is the main focus and employee retention is a secondary focus. According to a survey in Wills (2009) 79% of the full time employees would work for a company that either contribute or impacts the society positively. Furthermore, would 68% of the people in that group **refuse** to work for a company that is not socially and environmentally responsible.

BioMend will need to attract skilled and engaged employees for the process of duckweed harvest. The product offering has a number of social and environmental improving factors.

As mentioned in section 2.1, the European commission (European Commission, 2012) has since 2012 requested new value chains to support the bio-economy. This has affected both research and the national governmental goals. For Denmark, a large focus has been to increase the national production of protein for the large animal production. This is an area of social interest that this solution will support (see section 6.4.6), due to the protein accumulated in the harvested duckweed.

Duckweed removed from the lagoons of fish farms, has the direct socioeconomic benefit that allows for growth in the fish farm industry, due to the legislation of emission based environmental approval (Ministry of Environment & Food, 2016). All emission based fish farms, that perform better nutrient emission management, are allowed a larger fish production, which in turn generates higher profits, as seen in table 28. This will increase the efficiency of the industry of danish fish farms. Growth at fish farms leads to higher demand for labour in the local areas as well as lager overall export revenue.

The further socioeconomic benefits comes from affected industries further upstream in the supply chain. The impacted companies is the supporting manufactures of production equipment and fish fodder for the fish farms. Denmark has a strong position in export of fish fodder and ingredients for fish fodder, with an estimated yearly revenue of 4,9 billion DKK (Ministry of Food, 2013). Additional export of specialised technology for fish farms has an total export value of 1,5 billion DKK. In total, the supporting industries employ about 300 people (Ministry of Food, 2013) .

From an environmental perspective, the goal is to reduce nutrient emission to freshwater streams and eventually the surrounding oceans. As the nutrient emission is above the National goal (see section 6.1.1), set by the Danish government, this product offering can prove to be a promising tool. The fish farms that typically struggle to meet the environmental criteria, is often older, smaller and in the market segment of Traditional fish farms (see table 11). These currently practice under the legislation of feeding quota environmental approval, and need tools for better nutrient emission management that comes at a smaller initial capital investment. The proposed solution support this at no initial investment from the fish farms.

A side benefit of nutrient uptake through duckweed production is the later potential for reuse of these resources. As shown in section 4.4, this process will utilise all components of the plant. The nutrients captured in the duckweed are either in the press cake or in the protein juice. The case of press cake is used for biogas production. Excess from the biogas production could be used for a number of use cases e.g organic fertilizer, as seen in figure 5. In the case of protein concentrate, it is fed to animals. Excess from this production can be used as organic fertilizer as well.

Today is chemical produced nitrogen created through a power consuming process that account for about 4,3% of the worlds total CO_2 emission (Chai et al., 2019). Phosphorus is mined from rock materials. This process has the environmental impact's of excessive water usage, landscape changes, impacts on water quality through discharge of wastewater and air pollution through toxic and radioactive dust particles emitted during mining and processing, causing significant human health problems (Reta et al., 2018). Furthermore did the European Commission in 2015 declare: "One of Europe's major challenges in the 21st century is the availability of the irreplaceable natural resource phosphorus" (commission, 2015)

Due to these factors is it desirable to limit use of the virgin raw materials for fertilizer as much as possible.

The above mentioned contributions to both the society and the environment provide a solid moral basis for potential future employees to identify with BioMend as a company. The objective of the product offering is in line with both international and national goals for socioeconomic development at a macro- and micro economic level.

6.4.6 Ability to grow

The growth potential of this solution face a number of limiting and enabling factors. In this section, these will be evaluated and the ability to grow is then determined. The analysis of competition is viewed from two separate perspectives. The competitors within protein sources and the competitors within nutrients emission management solutions for fish farmers.

6.4.6.1 Source of protein

The protein sources used in Danish fodder production, stems from a mix of Danish produced and imported materials. The fodder consists of the following materials: cereals, oily seeds, legume seeds, tubers and root vegetables, dried plant products, roughage, other plants, dairy products and fish (Landbrug & fødevare, 2021). Of the above mentioned input materials ,an estimated contend of 10-17% is soy protein (Callesen et al., 2020) depending on the fodder type. Variation in prices of both the national and imported protein sources can influence the sales price of the duckweed. As Danish biorefineries aim to substitute the import of soy protein, the price development of soy protein is the factor with the largest potential impact. The marked of global soy production has increased, and has done so in the past years, as the global demand has grown. In the past 50 years, the production has grown from 27 to 269 million tonne. Furthermore, the global production is expected to increase to 515 million tonne in year 2050 (International, 2014). As shown in table 29 page 56, the total Danish import of soy was in 2018 above 1.7 million tonne. According to Callesen et al. (2020), 92% of the imported soy was used for fodder. This means that the marked for protein in Denmark is large, but has a lot of competition from global suppliers of soy. The supporting element of the competition for marked share, is that the Danish government are in favor of Danish produced protein.

A second supplier of protein in Denmark is the emerging marked of grass protein. This is a direct competitor to BioMend, as grass producers has 100% of the marked share as supplier to biorefineries. While the grass producers can be seen as competitors, they cam also be seen as a necessary enabling component. The context of this is that the biorefineries has started production due to the potential seen in grass. Without the previous research and now commercial facilities, it would be more difficult to find a feasible customer for duckweed. Furthermore, conversations with both Biorefine Denmark and Ausumgaard (Appendix A.3 and A.4) reveal that the biorefineries in Denmark had plenty of unused capacity as well as ability and wiliness to increase capacity. The disadvantage for BioMend is that it is a startup and will for that reason have less power to negotiate higher prices for the delivered duckweed.

6.4.6.2 Nutrient emission management

Water treatment technologies consist of tools and methods for fish farmers to utilise in order for better nutrient emission management. At the moment, a number of these technologies are legally permitted, as seen on table 30 below:

Method	Investment cost (DKK)	Yearly operating cost (DKK/year)
Slurry deposit	300.000	80.000
Bio-filter	350.000	10.000
Micro screens	400.000	20.000
Lagoon	600.000	50.000

Table 30: Legal requirements to cleaning measures (Ministry of Environment & Food, 2016; K. K. Hansen, 2021)

The above mentioned methods are the minimum requirements, but can be increased in scale if the fish farmer want to increase production. They are effective for nutrient removal, and are often seen as a method for better nutrient emission management. The disadvantage of these methods, is two folded. From a economical perspective, the investment cost of the solutions are high. This can prove to be an issue for fish farmers as it is difficult to rent money from a bank. The financial valuation of investments and assets at fish farms is very low. As Peter Holm explains, is it "hard for a bank to see the value of a lagoon, because a bank needs security like a potential resell value, but you can't sell a hole in the ground" (K. K. Hansen, 2021). The second disadvantage is seen from the perspective of resource utilisation. The methods listed in table 30, rely on the bio-chemical process of denitrification for nitrogen removal. This means that the nitrogen binds to oxygen and creates $N2O$ also known as Nitrous oxide. The nitrogen accumulated in the wastewater from the fish farm is removed through gasification. This an issue from an environmental perspective, as Nitrous oxide is a 298 times more potent greenhouse gas than CO_2 (change connection, 2021). Still the question stands, of whether the fish farmers would consider a solution like the one proposed in this business case, and what key factors weighs in on the decision. In a previous interview with Peter Holm, he answered that the price is the most important factor for him. After that comes the work time related to the solution. If he as a fish farmer need to allocate manpower to the solution, it would increase his operational cost.

The solution is still under development and the startup at this point does not hold a significant economical or customer based marked share within the Danish bio-economy. Therefore, the risk of a large company entering the marked of duckweed exists. The industry of both fodder production and agriculture in Denmark is large compared to the size of the country. In 2018, the revenue from compound feed for animal alone was above 9,3 billion DKK and the total revenue for animal feed was almost 24 billion DKK (Statistic Denmark, 2021). Some of the larges Danish companies within compound feed production is DLG, DLF and Danish Agro. BioMend need to mitigate this threat by increasing its ability to specialise within the area and create close collaborations with both fish farmers and biorefineries.

6.4.6.3 Enabling factors

The enabling factors that is in play are both the internal strengths of BioMend and the external opportunities. The analysis of this thesis showed that the concept of using duckweed as a protein rich biomass for both nutrient removal and food source for animals is a well proven idea. This has been reviewed both in scientific articles and in real life conditions. It furthermore shows that this concept has not yet been exploited for commercial purpose in Denmark at this point. Thus making the product offering unique for the marked of both fish farmers and biorefineries. Both markets show interest in the product offering, which makes a strong case for a customer base in Denmark. Due to the newness of the concept, it does deviate significantly from the competitors on the marked. The concept furthermore aligns closely with the customers needs and governmental goals for the industry. The overall environmental impact is positive both locally and globally.

BioMend consists of four people. Three of them graduated from a master in Environmental planning from Roskilde University in April 2021. The Experimental Masters thesis written by those thee was "Bioremediation - An experiment with duckweed". Furthermore has previous projects conducted by three of the four people from BioMend, that examined the political, legislative and environmental implications of the industry of fish farmers. The fourth person (co-author Kristian Klougart Hansen) has through the education, of Operations and Management Engineering at Aalborg University, had a specific focus on circular supply chains and latest developed the initial value proposition suggestion for BioMend in the Third semester project. This gives the team wide knowledge within the potential of biomass utilisation, from the perspective of environmental, social and economical influencing parameters.

From an external perspective, the collaboration with Peter Holm serves as an opportunity for BioMend. He has expressed that he would like BioMend to run the first technology validating demo projects on his fish farms. In his position as Chairman for the Danish freshwater fish farms, his trust and approval of the solution is an opportunity to better access more customers in the marked.

The political environment in both the European Union and Denmark has allocated resources to increase the bio-economy. This means increased opportunity for capital support form governmental funds as mentioned in section 2.2.2. BioMend have an opportunity to move further with the first demonstration at an industrial level, by receiving monetary support from funds. The three funds that fits the goal of BioMend the most is the Innovations Fond Denmark, MUDP and GUDP. All three funds provide soft funding for projects within all technology readiness levels. As mentioned in section 2.3, the next step for BioMend is to reach TRL5: technology validation in relevant environment. Through this demo project, BioMend will have the opportunity to get a closer relationship to customers of both fish farmers and biorefineries.

A SWOT analysis has been conducted, in order to give a better overview of the growth potential of the product offering. This can be seen in figure 17.

Strengths	Weaknesses
• BioMend has wide knowledge of the industry and has performed experiments showing promising results • Value proposition deliver both newness and uniqueness for fish farmers and biorefineries • The value creation delivered through the solution gives customers ability to grow • The solution has a positive environmental socioeconomical impact	• No significant capital holding in the start-up at this point • Total customer base has not been secured • BioMend is located in Copenhagen and all fish farms are located in Jutland
Opportunities	**Threats**
• Growing demand for ecoservices providing bioremediation and new protein value chains • Multi marked integration of circular supply chain • Collaboration with chairman of Danish freshwater fish farms • Concept is aligned with governmental and soft money funds' goals	• Significant price reduction of soy protein import • Grass production increasing capacity of biorefineries • Larger more established companies entering the marked of duckweed harvest

Figure 17: SWOT analysis of the product proposal

Through the SWOT analysis it was discovered that one of the biggest threats is entry of competing companies. Even though the idea of utilising duckweed in a new protein value chain is new, the idea can be copied by other companies. It is thus important for BioMend to move forward with the concept as fast as possible. Thereby, will the BioMend be able to acquire a solid and loyal customer base before other companies enter the market. Furthermore, is it important for BioMend to optimise the processes of harvest and transport going forward. This will increase their competitiveness, thus having a stronger position in the market.

In order for BioMend to further increase competitiveness. The startup should prepare to expand the potential sources of duckweed. This will lower the risk of losing the foundation for the business case. In the solution proposed in this business case, about 56% of the revenue will stem from fish farms and 44% from biorefineries. A potential new source of duckweed is the lagoon areas in human waste facilities. The barrier of this source, is the legal implications of the further use case for the duckweed, as human wastewater is under heavy legislative requirements (Nielsen et al., 2016).

6.4.7 Innovation and development of new technologies

When it comes to the case of harvest and sale of biomass, it cannot be argued as being a development of any new technology from BioMend. However, part of the value chain that the duckweed utilises is the sale of duckweed to the new biorefineries being build in Denmark. According to Morten Ambye-Jensen, the technology used in the biorefineries "is very new at this point, and is just about to be commercialised". The first biorefinery that has been build is Ausumgaard, which was build in September 2020. The second was Biorefine Denmark, which begun production in April 2021.

The act of utilizing duckweed can be argued as innovative, as it is not yet industrialised for anything yet. The different properties of duckweed makes way for its different uses, that being the innovative way of removing nitrogen and phosphorus from the fish farm lagoons, and the high amount of protein making it an lucrative and innovative new way of providing animals with protein rich fodder, instead of using commercial crops like soybean and corn. Furthermore can the use of duckweed in biogas production be seen as an innovative way of achieving a higher amount of produced gas from anaerobic digestion, as discussed in section 4.3.4.1.

Wills (2009) argues that being innovative will make staff look "outside of the four walls" to see firsthand how they are able to make customers reduce their environmental impact through the use of the company's products and services.

This can be applied on the case of BioMend as well, seen from both the perspective of BioMends customers, and those who have BioMend as a customer. In the first case, BioMend helps their customers reduce the environmental impact with the use of duckweed instead of energy crops like soybean and corn. Energistyrelsen (2021b) argues that the use of energy crops in biogas production makes the overall climate benefit of biogas smaller, compared to the use of natural biomass.

In the case of those who have BioMend as customers, such as the company transporting the duckweed, BioMend can help reduce the environmental impact of the transport of duckweed by making sure that the trucks wont drive to a biorefinery with unused capacity. Driving with a truck which capacity is not fully utilized can be seen as a waste. The same can be applied to when the truck have unloaded the duckweed and needs to travel back to another fish farm, with an empty truck. An incentive to reduce the amount of times a truck travels without load could be the truck taking waste materials away from the biorefinery, such as the fibre product for biogas production, in order to deliver it to a biogas plant, before driving to a fish farm.

Lastly, as described in section 2.2, Denmark is committed to the common goal of increasing the utilization of natural resources. With BioMend utilizing the natural resource that is duckweed, it can be seen as being in compliance with that goal.

6.4.8 Increased profit and shareholder value

As BioMend does not yet have any profits, an increase in them is hard to generate. However, Wills (2009) argues, "an increase in profits typically comes from the growth of a continuous improvement culture, the discipline of committing to proven process, attracting better and more productive employees, and the reduction/reuse of material use and operating costs."

With this in mind, it can be argued that BioMend could take preliminary steps that seeks to increase the profits of which was shown in section 6.4. These steps could include the adaption of a continuous improvement culture early on, and evaluating on how to optimize operations and reduce the amount of resources used. Possibilities are ones such as optimizing harvest of duckweed and transport of harvested duckweed to reduce costs, and to look into increasing revenue from removed nitrogen and phosphorus, and duckweed sold to biorefineries. However, as the costs and revenues that are calculated and presented are estimations, trying to plan even further ahead by trying to reduce the assumed costs, and thus increase profits, would be a challenge.

The break even analysis reveals that the profit per harvest increases as the harvested duckweed reach the maximum capacity of the container. It is for that reason important that the container is filled to it's maximum capacity every time a harvest is performed. BioMend will thus need to make an analysis of the duckweed content of a lagoon before initiating a harvest. As BioMend gets better at analysing/estimating the content of duckweed grown in the lagoons, the profit generation per harvest will increase.

Increased profit could furthermore be achieved through obtaining prices of several different hauliers in close proximity of the different fish farms.

The evaluation of increasing profits, or reducing costs, will be further discussed in section 7, regarding future research.

6.4.9 Executive summery of business case

The executive summery gives an overview of the business case divided into the eight areas. The summery can be found in table 31 page 64

Executive summery of the Business Case

1. Product offering Nutrient emission management for fish farmers Supplier of protein rich biomass for biorefineries The key activity is to perform the harvest and transportation of Duckweed from fish farmers to bio refineries	**2. Economical evaluation** The total marked potential in Denmark gives an estimated revenue between 1.371.665 DKK and 5.525.852 DKK. Where the Net Profit is estimated to be between 340.787 DKK and 1.374.224 DKK The break even analysis is calculated for the case of one harvest. This shows a break even point at 12.912,72 kg pr. harvest. As the total capacity of the container is 18.000 kg will this solution generate profit when the container is more than 71,7% full
3. Socioeconomic evaluation Fish farmers on the emission based environmental approval will with this solution be able to increase production. At removal of 56kg nitrogen and 4,9kg phosphorus will the fish farmer be able to produce 1.100kg fish. This result in an increased profit of 12.395DKK. For Denmark will the increased utilisation of national produced protein resources decrease the need for imported soy. From a socioeconomic perspective will decreased import of soy be economical beneficial for Denmark	**4. Customer Loyalty and Attraction** BioMend will gain attraction from the fish farmers by delivering an affordable solution to better nutrient emission management. The solution gives the opportunity to lowering the total emission of both nitrogen and phosphorus. By increasing nutrient emission management fish farmers also have en opportunity to increase production. The Danish biorefineries is newly started and the inclusion of duckweed as biomass will increase their throughput.This is important for the biorefineries as too low utilisation of the equipment will lead to economical loss
5. Employee Attraction and Retention The solution proposed by BioMend aim to deliver positive impact both from a environmental and socioeconomic perspective. This is aligned with both international and national goals for the environment and economy.	**6. Ability to Grow** BioMend's ability to grow is closely tied to both the available source of duckweed at fish farms and the demand for biomass from biorefineries. It has be identified that fish farmers have a clear incentive to support the growth of BioMend as the benefit gain for the fish farmer outweighs the negativ implications. BioMend need to exploit the newly started marked of biorefineries. Through interview have all existing biorefineries explained that they would be willing to accept duckweed as biomass. This means that the key contributors will support BioMend's growth.
7. Innovation and Development of New Technologies This solution is in the forefront of the development of new protein value chains in Denmark. The first step enabling this in Denmark is the comercialising of biorefineries. The use of duckweed has never been done at a commercial scale in Denmark. The innovation of this new technology will not only be within BioMend, but will also expand the innovation within the biorefineries, as they need to adjust to wider range of biomasses. This will potentially open for the development of new unknown sources of protein.	**8. Increased Profit and Shareholder value** As a startup does BioMend have a number og links in the value chain that can be improved over time to increase profit and value. It is especially the core activities that can influence the profit and value. BioMend will focus on continuous improvements of both the processes of duckweed harvest as well as implementing optimised transportation deals with hauliers. The profit can be further increased by utilising the maximum available space in the container each timer a harvest is performed, as the break even analysis shows that this is a important factor in maximum potential profit

Table 31: The Executive summery of the Business Case

7 Future Research

There are numerous ways to achieve the solution that Biomend can provide, that is the utilization of duckweed as a means to remove nitrogen and phosphorus from waste wasters, together with the sale to biorefineries, in order to produce protein rich fodder, and a fiber product for biofuel production.

This section will revolve around the possible ways that BioMend can and should realize the solution.

7.1 Suggestion for further action for BioMend

In order for BioMend to realise the idea of using duckweed for Protein production in a biorefinery, a number of actions are required. In this section, the necessary actions will be analysed.

BioMend need capital investment to move further to a TRL5 demonstration, as explained in section 2.3 and 6.4.6. It is suggested that BioMend proceeds with the development of the new value chain for duckweed with support from governmental funds. Here, Innovation found Denmark, MUDP and GUDP would be a good fit with the goal of BioMend. MUDP has in the past years been involved in environmentally improving projects, and has supported the development of the first biorefineries with 100m dkk. MUDP has application deadline in May every year. The special focus areas of the environmental technology projects in 2021 was (1) Climate, (2) Circular economy and recycling, (3) Nature and biodiversity and (4) Clean water and clean air. As the solution of BioMend matches more than one of these requirements, it would be a fitting fund to apply for capital funding. GUDP also has application deadline in May for the first round and a second application round in September. Figure 18 is a spider web diagram showing the specific requirements to the applicants and how they are measured. Depending on how well the applicant's project score, the chance for funding will either increase or decrease. Within each of the areas of sustainability.

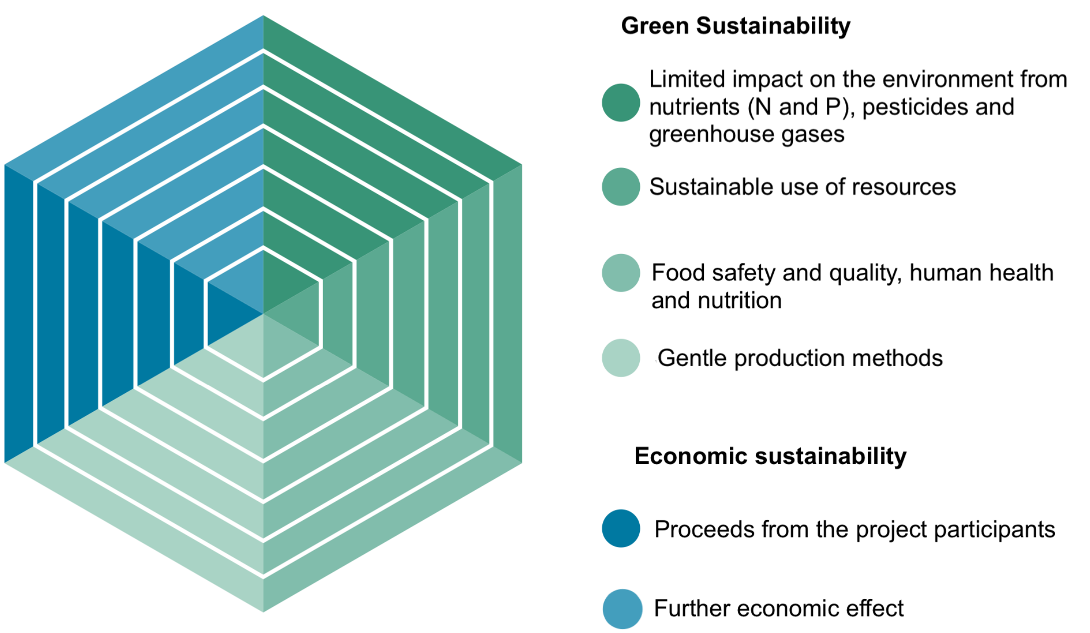

Figure 18: Application requirements for the GUDP fund (GUDP, 2019)

7.2 Increase in profits

The revenue that Biomend is able to gain from the removal of N and P was calculated to be 0,064 DKK from 1 kg removed duckweed, and with the calculated growth rates, a yearly revenue at 772.423 conservative and 3.111.762 liberal.

It was furthermore presented in table 28 that a fish farmer was able to earn 12.395 DKK as a result of having 56kg nitrogen and 4.9 kg phosphorus removed from their wastewater lagoons. As the price that the fish farmer would pay Biomend for the removal of the N and P is 805 DKK, which is 6% of 13.200 DKK (the revenue from the sale of 1.100kg fish at a price of 12 DKK/kg), it can be argued that a fish farmer has a relatively high revenue compared to expenses when it comes to the removal of N and P.

Because of this, it can be argued that an increase in the price of removal of N and P could be possible for Biomend to achieve, based on the fact that a fish farmer would still have quite a high profit, even if the price doubled, from 10 and 50 DKK to 20 and 100 DKK for the removal of 1kg nitrogen and 1 kg phosphorus, respectively. This would increase the price from 805 DKK to 1610 for the removal of 56kg nitrogen and 4.9 kg phosphorus. From the fish farmers perspective, this would then earn them a total of 11.590 DKK, while the increase in price would increase the conservative revenue from the removal of N and P from 772.423 DKK to 1.544.846 DKK, and the liberal revenue from 3.111.762 DKK to 6.223.524 DKK.

Process	Cost (DKK)
Harvest of duckweed (conservative)	-165.078
Transport of duckweed (conservative)	-865.800
Revenue from removed N and P (conservative)	1.544.846
Revenue from sale of duckweed to Biorefine Denmark (conservative)	599.242
Earnings (conservative)	1.113.210

Table 32: Total conservative market potential for the harvest, transport and sale of duckweed to Biorefine Denmark with a double in price of N and P removal

Process	Cost (DKK)
Harvest of duckweed (liberal)	-665.028
Transport of duckweed (liberal)	-3.486.600
Revenue from removed N and P (liberal)	6.223.524
Revenue from sale of duckweed to Foulum biorefinery (liberal)	2.414.090
Earnings (liberal)	4.485.986

Table 33: Total liberal market potential for the harvest, transport and sale of duckweed to Biorefine Denmark with a double in price of N and p removal

With the doubling in price that BioMend receives from the removal of nitrogen and phosphorus, they would more than triple their earnings.

It can thus be argued that a future increase in the price that fish farmers pay for the removal of nitrogen and phosphorus, would be feasible for BioMend to negotiate.

7.3 Duckweed for human consumption

As stated in the end of section 4.3.2, the Novel Food Catalogue has listed Lemna minor as the only representative of duckweed with potential for human consumption. To add to this, during the interview, Robert Mouritsen claimed that the production equipment used by Biorefine Denmark is created to operate within the legislative requirements for human food protein, and that they right now only are waiting for the protein source produced by Biorefine Denmark to be approved for human consumption, from a legal perspective.

Lastly, Foods (2021), which is a company based in The Netherlands, has produced protein concentrate from Lemna minor. This product can be used as a taste enhancer in savoury products, such as soups and sauces, meat replacements, bakery products, hearty snacks and also for use in protein enriched products for sportsmen and the elderly.

With this in mind, it can be argued that the utilization of the Lemna minor grown on the lagoons of Danish fish farms has potential of being used for human consumption, and can even be produced by Biorefine Denmark. It can therefore be of high interest for BioMend to actively try and try and enter the human food market in the future, in order to broaden their market potential of duckweed from not only being a feedstock for animal fodder and biogas, but also a feedstock for human consumption. However, it can be expected that duckweed used for human consumption would have higher qualitative requirements, compared to the use for animal fodder and biofuel.

8 Discussion

This section seeks to discuss the various choices made by the researchers throughout the thesis, and what impact choosing otherwise might have resulted in.

8.1 Choice of methods

As stated in section 5.1.3, the researchers decided on the research strategy that is a case study. However, as there are other choices regarding the research strategy, one could argue that the choice of a different one would have had a different impact on the thesis as a whole. Looking at figure 9, the choice of an experiment as an approach to a research strategy could be of interest to discuss.

The difference between a case study and an experiment is that a case study seeks to perform an in-depth analysis of a single case, where an experiment seeks to manipulate two or more variables, to see if there is a correlation between them. In an experiment, the two variables are the independent and dependent variable. An example of those two variables could be the use of independent duckweed in biorefining, to see whether the dependent press juice and fibre product had any major changes in protein and starch, compared to the use of grass. Another example could be the performance of nutrient starvation on duckweed in order to see if the process actually has any major impact on the starch accumulation in the duckweed.

As the researchers did not know about the practice of biorefining of biomass into protein rich fodder, or that the performance of nutrient starvation have an impact on the nutrient composition on duckweed at the beginning of the thesis, it can be argued that the choice of an experimental research strategy would have had diminishing results, as the researchers did not have the necessary knowledge about the area in order to conduct the experiments. Because of this, the choice of a case study, enabling the in-depth analysis of the case through the literature review and market analysis, proved to be a reasonable choice for this thesis.

However, should the researchers choose to conduct any further research in the future, the choice of an experimental research strategy could prove to be lucrative, as the researchers now have knowledge about the potential of the biorefining of duckweed, and the possibility of increasing the nutritional value of duckweed by performing the nutrient starvation.

An experiment of the biorefining of duckweed could serve as a Proof of Concept, that showcases the actual possibility of turning duckweed into protein rich fodder, before BioMend continues with the realization of their solution.

8.2 Delimitation of bioethanol

As decided in section 6.2.2, the use case of Lemna minor as a feedstock for the production was deemed unfeasible, due to the low starch content.

However, as discussed in section 4.3.3, one could increase the amount of starch in duckweed by performing the process known as nutrient starvation. By changing the medium in which the duckweed is growing, from a nutrient rich one to a one with substantially less nutrients, such as tap water, the duckweed begins to accumulate higher amounts of starch as a reaction. Furthermore does the increase of light also result in accumulation of starch, as discussed in section 4.3.3.

With this, it can be argued that a business case revolving around the growth of Lemna minor with the goal of using it as feedstock for bioethanol, could be possible. Ge et al. (2012) argues that they achieved starch content of 10-36% in Lemna minor by nutrient starvation, which is a significant amount compared to the low amounts of starch achieved from nutrient starvation by other authors, as discussed in section 4.3.3.1.

As the market analysis of bioethanol was halted quite early in section 6.2.2, the market potential of bioethanol in Denmark was not further analysed, and the researchers did thus never get any indication of whether the sale of duckweed as a feedstock for bioethanol production would be feasible, with the performance of nutrient starvation.

Performing nutrient starvation is a resource heavy process, that requires the physical movement of large amounts of duckweed into a new basin or container medium, that not only has to have less nutrients than wastewater, but also requires the ability to produce a higher amount of light than natural light is able to, in order to accumulate as much starch as possible. Furthermore did the increase in temperature show to have a positive impact on starch accumulation, meaning that the container should also be able to increase the temperature of the water, and to ensure that the temperature stays constant with minimal input, an indoor facility could be argued as needed.

With this in mind, one can assume that the acquisition of such products will end up with quite a high cost, compared to just growing them in wastewater lagoons present at fish farms. The basins can be seen as a one time investment, but the constant artificial lightning and temperature regulation can be assumed to be quite power consuming.

Experiments conducted by Nørgaard et al. (2021) showed a 0,45kWh/m^2/day lightning solution had a price of 16,2 DKK/m^2/day.

However, without knowing the revenue that the selling of duckweed for bioethanol feedstock purposes would generate, it cannot be dismissed that the performance of nutrient starvation would not be feasible. The increase of starch would furthermore also most likely be of interest to biorefineries and biogas manufacturers, as the fiber product then also would end up with a higher amount of starch, thus producing more biogas.

8.3 Assumptions and estimations

The researchers has made various assumptions and estimations throughout the thesis regarding the protein and starch content of Lemna minor, the growth rates that should be achieved from Lemna minor grown in Danish weather conditions, the revenue and costs associated with the harvest, transport and sale of duckweed, etc.

The assumptions and estimations has been based on information acquired from primary and secondary quantitative and qualitative sources, such as the conducted interviews and reviewed literature. As to not just assume the conclusions of one author being as is, such as the growth rate of duckweed, numerous experiments was reviewed by the researchers, in order to draw conclusions on what one can assume would be an adequate growth rate of Lemna minor grown in Denmark. The same can be argued for the protein and starch content of Lemna minor and duckweed in general. With Landolt and Kandeler (1987) arguing that the protein and carbohydrate content of all species of duckweed varies from 6,8 - 45% and 14,1 - 43,6% respectively, it can be argued that there will be a degree of uncertainty on the protein and carbohydrate content that the researchers assumed for Lemna minor. In order to confirm the actual nutrient composition of Lemna minor, BioMend could and should go out in the field and conduct tests in order to determine them.

Regarding the assumptions on revenue and costs associated with the harvest, transport, and sale of duckweed, those numbers also have a degree of uncertainty. As Foulum Biorefinery is a research facility, the researchers did not take their offer of 1 DKK/kg wet matter as being a realistic scenario, based on the fact that Biorefine Denmark would only pay 1 DKK/kg drymatter, 20 times less than Foulum. Furthermore, regarding Biorefine Denmark purchasing duckweed from BioMend, as no direct agreement has been made between BioMend and Biorefine Denmark, one cant be sure that they actually have in mind to pay the informed price of 1 DKK/kg dry matter, should BioMend choose to realize the presented solution.

However, as the thesis was limited time wise, the researchers thus also had limited time to conduct market research and contact possible customers that would be willing to purchase duckweed.

When contacted, Ausumgaard biorefinery did not have any price that they would be willing to purchase duckweed at, as they had in mind to only use grass grown from their own fields. The researchers was thus left with the prices acquired from the interviews with Morten Ambye-Jensen, and Robert Mouritsen, as a representation of what revenue BioMend can generate from the sale of duckweed.

8.4 Evaluation of research questions

Did we manage what we wanted with the RQ Could the rq hav been better worded Were they inclusive enough Did they give intensive for research Did they have relevance for the study

8.4.1 Potential use cases

The first research question was answered in the literature review, found in section 4. In this review, the numerous use cases of duckweed were outlined. This section will discuss the applicability of duckweed in use cases where the use of soybean and corn is most dominant. Secondly, the specific content of Lemna minor in regards to the use cases, will be discussed.

The literature on the use of duckweed as a supplement to conventional fodder has been proven viable for a number of different animals. However, poultry has shown worse result at the use of duckweed in it's dried form compared to soybean meal. It could be argued that duckweed is not a suitable substitute for soybean meal for these animals at all. One factor that is not taken into account is the protein content of the two different fodder compounds. Soybean meal has a crude protein content of 33 to 49%, where dried duckweed has a crude protein content of between 6,8 to 45% (Landolt and Kandeler, 1987).

In relation to this specific project, Lemna minor will be converted to a protein paste with a total potential protein content of about 50%. This makes the duckweed product more potent and therefore better suited for animal feed. Furthermore can it be argued that the protein concentrate from the biorefineries have a wider range of applications than the untreated dried duckweed.

As the focus of the literature review was to gain insight into duckweed as a whole, and thus its use case, some species besides Lemna minor was also mentioned, such as Spirodela polyrhiza. The reason for this being that Spirodela polyrhiza is a duckweed species that has very favourable contents of starch, as discussed in the literature review. With measured starch contents of 20% to 45,8% dry based after the performance of nutrient starvation, it out performs Lemna minor in regards to starch content. Because of this, it can be argued that there are other species of duckweed that would perform better in the use case of production of biogas, compared to Lemna minor, as starch is the important component in the production of biogas. However, as Spirodela polyrhiza is not as common in Denmark compared to Lemna minor, the literature review concluded that the continued focus of the thesis would be Lemna minor.

8.4.2 Market investigation and customers for Lemna minor

As the market investigation had direct influence from the use case of duckweed found from the literature review, the customers and industries that was investigated was the animal fodder, biofuel and biorefinery industries. As the researchers limited the market investigation to those industries, it can be argued that some other potential markets were not investigated, such as the market for human consumption. As mentioned in the literature review, section 4, the Novel Food Catalogue has listed Lemna minor as the only potential duckweed for the use of products that can be consumed by humans. Both Foods (2021) and LENTEIN (2021) produces products for human consumption from duckweed. It can therefore be argued that the market investigation could have included the investigation of those two companies as potential customers for BioMend. However, as Foods (2021) and LENTEIN (2021) are based in The Netherlands and USA respectively, and not in Denmark, contacting them for the potential of being customers, would be out of scope for this thesis.

8.4.3 Decision on the value chain

There are multiple different value chains that the biomass of duckweed can contribute to, as shown in the literature review. From a Danish perspective, the possibilities for use cases are more limited. For that reason, two main factors contributed to the choice of use case: the best suited use case for this biomass and the available sources in Danish context. From the perspective of gaining the highest possible value of the biomass, the value chain of fodder protein is a more valuable resource than biofuel. The aspect of availability of potential customers in Denmark is limited to two markets, namely the biogas plants and biorefineries. It was discovered that the industry of biogas has a lot of competition. It was furthermore discovered that biomass delivered to biogas plants in some cases came at a cost for those delivering the biomass. This was a clear disadvantage in regards to biogas plants as a customer. In relation to biorefineries, the information highly available through interview of the direct sources. This made the foundation for a more thorough analysis of biorefineries as customers.

8.4.4 Business case

There are numerous ways to conduct a business case, with different frameworks available. The choice of framework should be dependant on the purpose and solution that a company affiliates itself with. As BioMend is a startup that revolves around the utilisation of the natural biomass duckweed, with a sustainable view in mind, the choice of framework presented by Wills (2009), can be argued as being a reasonable choice. The reason for this being that this framework revolves around a business case with sustainability in mind.

The results shown in the business case is based on the previous performed literature review and analysis. As the economical results is derived from a number of calculations based on assumptions, the reliability of these is important to discuss. The financial market potential has been calculated on the prices from both Morten Ambye-Jensen (Foulum) and Robert Mouritsen (Biorefine Denmark). Even though the prices from sold biomass to Foulum is significantly higher than Biorefine Denmark, the long term perspective of selling duckweed to commercial facilities has been prioritised.

The other aspect is the conservative and liberal market potential. There is a wide gap between these two calculations. This is due to the use of available sources of growth rates presented in the literature. It would have been preferable to have a specific result for Lemna minor growth rate in Denmark during a yearly time frame. Alternatively could an experimental approach potentially give a smaller gap in the economic calculations. This was in the meantime not chosen due to the time frame of the thesis, and the knowledge that the researchers possess. Furthermore was the season in which the thesis was conducted not suitable for such outdoor experiments, as the maximum growth rates is seen during the summer.

9 Conclusion

The use case for duckweed was identified through the review of literature. A total of three use cases was identified, those being the partial adding of fresh or dried duckweed to diets of animals in agri- and aquaculture, feedstock for the production of bioethanol and feedstock for the production of biogas. Furthermore can a biorefining of raw duckweed separate the biomass into two products: A protein concentrate and a fibre product, used for animal fodder and biogas production respectively, instead of just using raw duckweed for either animal fodder or biogas feedstock. Lastly was Lemna minor determined to be the duckweed species of focus for the thesis, as that is the species that is most abundant in Denmark.

In Danish context, the analysis provided an overview of tree potential customers for Lemna minor. Firstly was the direct sales as animal fodder assessed. Denmark has a large production of pigs, sheep and chickens, which are all animals that could utilise the duckweed as fodder. Fodder producing industries and farms is therefore concluded to be a potential customer.

The analysis of bio-ethanol in danish context concluded that the use of Lemna minor was not suitable for the production of bioethanol, due to the low amount of starch. The marked of biogas production in Denmark is large and still increasing in size. More than 186 biogas plants is currently operating in Denmark. The vast majority of these biogas plants are located in Jutland, where the fish farms are also located. It is concluded that biogas plants could be a potential customer.

Lastly does the the newly started marked of biorefineries provide a high degree of utilisation of duckweed, by producing protein concentrate for animal fodder and a fibre product for biogas. As spokespersons from two refineries, Foulum Biorefinery and Biorefine Denmark, showed interest in the biorefining of Lemna minor, it is concluded that they are potential customers as well. The biorefining of duckweed makes the scenario of utilisation of raw duckweed for either animal fodder or biogas feedstock obsolete.

The suggested value chain consist of two core activities. First is the process of duckweed from the lagoon areas at fish farms. The cost of harvest of 18.000 kg duckweed is estimated to be approximately 250 DKK. The second process is the transportation of the harvested duckweed from a fish farm to a biorefinery. The cost of transport is estimated by a Danish haulier to be 1.300 DKK for the transport of one container at 18.000 kg.

The two revenue generating elements of the value chain are the fish farmers and the biorefineries. The fish farmers pay for the service of bioremediation through the removal of nitrogen and phosphorus. The revenue generated from the harvest of 18.000 kg duckweed, and thus a fully loaded truck of is approximately 1.160 DKK. The biorefineries pay for the delivered biomass. The revenue generated from the sale of 18.000 kg Lemna minor to biorefineries is 900 DKK.

The business case presented the total market potential of duckweed harvested on all danish fish farms. The profit that BioMend is able to generate with the solution, is a product of the harvest, transport and sale of duckweed to Biorefine Denmark. The profits are dependant of the conservative and liberal growth rate of Lemna minor. The potential conservative yearly profit is 340.787 DKK, while the potential liberal yearly profit is 1.374.224 DKK.

The break-even for a single harvest of duckweed is approximately 13.000 kg, in order for BioMend to be able to generate profits. As the truck used for transportation has a capacity of 18.000 kg, a fully loaded truck would generate a profit of 512 DKK. In conclusion, it will be possible for BioMend to make a profit when harvesting above 13.000kg of duckweed in one harvest.

The business case showcased, from a socioeconomical perspective, that a fish farmer is able to produce more fish as a result of BioMend harvesting Lemna minor from their lagoons, and thus generate more profit. Furthermore did the business case showcase, from an environmental perspective, that the solution presented provides a low cost solution for better nutrient emission management.

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Appendices

A Interviews

A.1 Interview of Peter Holm

How is the maintenance of the lagoon areas conducted at the moment?
Peter Holm: Twice a year, we use either an excavator or by using a dredging tool attached to a tractor. This process will remove sediments like plants and dead plant material from the lagoon.

Where does the sediments in the lagoon come from?
Peter Holm: It is a combination of dead plant materials that grows in the lagoon and bio-waste from the fish containing Phosphorus. This needs to be removed twice a year to ensure the right water flow and to maintain a nutrient emission that meets the legal requirements.

What type of plants grow in the lagoon area?
Peter Holm: The two main plants are Duckweed (Lemna minor) and Sweet-grass (Glyceria). But other plants like water-starwort (Callitriche palustris) grow in smaller quantities. You should try to investigate if the Sweet-grass could be utilised as feed for animals.

What do you use the removed sediments for?
Peter Holm: We do not use it for anything. We usually place it in a pile at a convenient place at the fish farm. For us it is only a time consuming process that costs us money.

What happens if you do not remove the sediments?
Peter Holm: First and foremost is it a legal requirement, but if we do not remove the sediments, the water flow in the lagoon will be restricted and the nutrient emission will rise over time.

What type of emission is the largest problem for fish farmers?
Peter Holm: In some periods of the year the phosphorus level increases. That happens because the plant material in the lagoon decomposes, and emits some of the nutrients that was collected during the growth season. In general for the industry, it will typically be phosphorus emission that comes close to the legal limit for emission. What happens is that if the lagoon is too small, BOD and nitrogen provides the largest risk for nutrient emission. Where larger lagoons will have no problem mitigating the risk of too high Nitrogen and BOD levels. Here the phosphorus emission is the problem.

From a logistical point of view, are the lagoon area accessible?
Peter Holm: Yes, because all fish farmers need to remove sediments from the lagoon once in a wile. Furthermore does all Fish farmer have a dredging tool at their disposal. This could be used to harvest the Duckweed if that is what you want. We use a hydraulic pump from a local machine factory. They could also help you make the harvest device for you. The price for the dredging tool is about 15.000DKK. There are low maintenance on that device.

What economical value of removal of Nitrogen and Phosphorus from a fish farm - What are the fish farmer willing to pay for the service?
Peter Holm: The fish farmer would be willing to pay about 10 DKK pr. kg nitrogen and 50 DKK pr. kg phosphorus removed from the lagoon. Because phosphorus is the largest problem for us.

By implementing an effective harvest of biomass, how fast would a fish farmer be able to increase production?
Peter Holm: The fish farmer could implement emission based environmental approval for the

production rather fast. By knowing the time of the year where the nutrient removal peaks via biomass harvest in the lagoon, the fish farmer can adjust the increased feed in that period. In that way the solution would have a positive impact on the yearly fish production.

What type of solution would a fish farmer benefit from in regards to the lagoon?
Peter Holm: What I see as a potential is a complete solution where both the plant material containing a lot of nutrients is removed gradually as it covers the lagoon. But at the same time if you bring in a solution to re purpose the sedimentation from the lagoon, will it increase the efficiency of lagoon. This solution could also be implemented on wet land areas that is implemented in a lot of places.

A.2 Interview of Morten Ambye-Jensen

What type of biomass do you use and for what purpose?
Morten Ambye-Jensen: We make make Green bio-refinery. That is the extraction of protein from biomass. In our case, the biomass is mostly Grass. It is important for us to utilise all potential Biomass fractions that is part of the plant. The element of the biomass that is not refined to protein concentrate for human or animal consumption, is used for bio-energy.

What is your process?
Morten Ambye-Jensen: We press the fresh biomass to get a plant juice. This juice will typically contain half of the protein from the plant. Then the protein is separated from the plant-juice. This type of protein can be given to monogastric animals[17] like pigs and chickens. This type of protein can also be upgraded for the use of human consumption. The residue that is not used for protein is converted to biogas in an biogas reactor.

In the biorefinery, have you used the biomass for production of bioethanol?
Morten Ambye-Jensen: We have studied the potential use for specifically bioethanol, but because the bio-ethanol is a relatively low-value product, it has for us made more sense to utilise the biomass for something else with a higher value. Bio-ethanol is seen as a low-value product because it can be substituted for oil made ethanol. But we have researched the potential use for bio-ethanol production of the residue that is left after extracting protein from the biomass.

The process of making bioethanol can be done by utilising the carbohydrates from the biomass. First the biomass will need to be fermented by using an industrial grade yeast for the ethanol production. Later can the liquid be distilled and thereby, extracting the bioethanol.

As a rule of thump would it be possible to extract 90% of the carbohydrates in the biomass to bio-ethanol.

In duckweed do we typically see a concentration of carbohydrates at about 12.5% would you consider this feasible for bio-ethanol production?
Morten Ambye-Jensen: No, i would consider this as a low concentration of carbohydrates for the purpose of making bio-ethanol. Especially in context of the low prices for conventional produced ethanol from crude oil.

In duckweed do we typically see a concentration of protein at about 20% would you consider this feasible for protein production?
Morten Ambye-Jensen: Yes, I would consider the main product, from a biomass like Duckweed, to be protein for feed. Furthermore, would the excess bio-material be uses for bio-gas and not bioethanol.

Do you have any economical evaluation of the protein production in your set-up?
Morten Ambye-Jensen: Our calculations are based on a number of assumptions:

1. The grass that we would use is produced and delivered at a price of 1DKK/kg fresly harvested grass
2. It is treated at a bio-refinery plant
3. We produce bio-gas from the excess bio-materials, as well as the residue from the protein separation process
4. Lastly the concentrated protein (protein content of about 50%) is sold as organic feed (in that way the protein will substitutes organic soy-protein that have a higher market price at about 6DKK/kg - this is approximately twice the price of conventional soy-protein)

[17] Animals that has a simple single-chambered stomach

Under the above mentioned assumptions, it will be possible to generate profit from grass as input at a bio-refinery. I would say that this concept at this point has the biggest relevance within organic protein production. With that being said, is our expectation that it will be feasible for conventional protein production later when the utilisation of excess value streams see a higher yield or create higher value concentrated protein.

Would your profit margin increase if you have a larger production facility?
Morten Ambye-Jensen: Our problem at the moment is that we produce a lot of protein mass that will rapidly decrease in value when stored. Therefore, do we need to send our product directly to the farmer right after production. These circumstances provide a challenge for larger production facilities.

At our production facility do we need a input of biomass at about 40 to 50 metric ton pr hour to ensure appropriate utilisation of the production capacity (measured in fresh green biomass).

Where do you see the potential for Duckweed in the protein value chain?
Morten Ambye-Jensen: I would suggest Duckweed to have a place as a part of the other newly found protein sources like grass. This is because I see it as a challenge to reach high enough biomass harvest pr. day and year to construct a biorefinery that is driven only by the input from the duckweed production.

Do you have any current prices for biomass delivered to biogas facilities?
Morten Ambye-Jensen: No, this is a difficult market to assess a specific price for. It is because some biogas plants receive high value products which they pay for. Some biomass types are received without payment and certain types of biomass will cost you money to deliver to a biogas plant. Furthermore does the price depend on what type of biomass that is usually delivered at the independent facility.

I would suggest that you make the calculation on the potential methane gas production from your product (duckweed) and from that, assess the potential value created because the price for methane is widely available.

Are there any companies that is specialised in bio-refinery at an industrial scale?
Morten Ambye-Jensen: Yes, but the technology is very new at this pooint and is just about to be commercialised. A commercial bio-refinery was build in September 2020. This facility relies on organic sources of green biomass. It is placed at a large farm, called Ausumgaard in the western part of Jutland. In collaboration with Vestjyllands Andel have they created the largest bio-refinery in Denmark so far.

A second bio-refinery is under construction at the moment, and will begin production in May 2021. This facility is owned by a consortium of companies that have founded a new company called Biorefine Denmark. One of the co-founders is DLG, DLF and Danish Agro.

A.3 Interview of Robert Mouritsen

What is the production method used at your facility?
Robert Mouritsen: The fresh biomass (grass) is first broken down all the way to the cell level, where protein and water is separated from the plant materials containing fibers. This could be called a biorefinery.

Do you have any specific requirements to the water content of delivered biomass (grass)?
Robert Mouritsen: No, we do not have any requirements regarding that.

What is the typical water content of grass?
Robert Mouritsen: We actually measure the dry mass of the delivered grass. That is usually between 10 and 30%. But I will say that grass transported with too high water content can be difficult to transport. The reason for this is that large amounts of biomass in a delivery truck will compress the plants and thereby actually press out some of the protein in the plant.

What is the typical protein content of grass?
Robert Mouritsen: The latest shipment from yesterday was about 18-19% of the dry matter. This protein content should ideally be the minimum protein concentration.

Does the content of Lignin have any effect on your production?
Robert Mouritsen: No, because this is removed in the process of separation.

What is the typical prices for grass that you buy from farmers?
Robert Mouritsen: There is not a published standard price for the biomass. But compared to your previous prices, they are higher than last year. The reason for this is that our new production method is better at extricating the crude protein from the biomass. The price is defined by a number of factors: the protein content, the total available mass of grass and the specific location of the source due to transport costs.

For the sake of your calculated business case, would I suggest that you use a universal sales price of your biomass of 1DKK/kg in dry mass. It should be noted that this price usually in the industry is at a protein content of 20%. The price mentioned would be either increased or decreased by 0.06DKK/kg pr. percentage the protein content is either above or below 20% respectively. This price is without the cost of transportation.

Will the nitrogen and phosphorus have an impact on your production?
Robert Mouritsen: No, I have not herd anything about that being an issue.

What is your production volume?
Robert Mouritsen: In the current setup are we able to handle about 50.000t/year biomass. They production facility is new but we plan to scale up production in the years to come, depending on the available supply of biomass. We will be able to double our production if needed.

Would you consider duckweed a viable contribution to your production?
Robert Mouritsen: I can't see any issues with that type of biomass in our production. As long as the biomass is delivered in a fresh condition to our facility. I believe that the machines would be able to extract the protein from the plant, just like with grass, without problems.

From the perspective of our capacity is it not a problem as well. Our production facility have plenty of capacity for the amount of duckweed produced at fish farms. Furthermore, are we able to scale up production to the double if necessary.

What do Biorefine Denmark use the concentrated protein for?
Robert Mouritsen: First step is to dry the protein mass to 10% water content. After that is the protein mass able to be stored and sold to fodder production companies. This can be used

as a substitution for soy-protein and sold as fodder for chicken, swine and calf's. The size of our production is estimated to replace about 10% of the total soy-protein import over time.

Do you have the potential to upgrade the protein production?
Robert Mouritsen: Yes, All of our production equipment is actually created to operate within the legislative requirements for human food production. Right now we are just waiting for our protein source to be approved from a legal perspective.

Are you open for further discussion and collaboration?
Robert Mouritsen: Yes, you are welcome to contact me regarding questions to our processes and I would like to hear more about your project when you start to harvest duckweed. But i can't promise, at this point, that duckweed will be included in our production, as this will require tests for the biomass first.

We will be open to collaborate if you bring a test of your biomass if you are able to deliver 2-3 ton of duckweed. Then we would be able to determine the value of duckweed in our production.

If we should start a complete production run for protein extraction of duckweed would we need a larger amount of biomass. The requirement would be $40t$ to $50t$ wet weight (raw biomass).

A.4 Interview of Holger T. Lauritsen

What is the processes for your biorefinery?
Holger T. Lauritsen: We harvest the grass on our own fields. We have about 300 acres that will be harvested up to five times a year. From there will the grass enter the biorefinery. First step is a screw press. From there will the protein rich juice be separated.

What is your current capacity? Holger T. Lauritsen: We should have an capacity at about 20 ton pr. hour

What is the water percentage of the grass you use?
Holger T. Lauritsen: We actually do not have an exact measurement of this but i would guess that it is about 15%

Do you have a price that you pay for grass delivered from nearby suppliers?
Holger T. Lauritsen: Not at this time, as we mainly use our own grass. We have a few other suppliers, but i can't share the price at this moment. In part because we do not have a fixed price at this point.

Would you be interested in duckweed for your production?
Holger T. Lauritsen: I would say that any biomass with protein would have interest. I would like to hear from you, when you have a product. Then we can discuss the potential.

B List of Biogas plants in Denmark

The following 5 pages is a list of all active biogas plants in Denmark as of 2020 (Energistyrelsen, 2020).

Liste over biogasanlæg i Danmark, 2020

Type	Navn
Renseanlæg	BIOFOS, Rensningsanlægget Lynetten
	BIOFOS, Damhusåen Renseanlæg
	BIOFOS, Spildevandscenter Avedøre
	Mølleåværket (tidl. Renseanlæg Lundtofte)
	Stavnsholt Renseanlæg, Farum
	Måløv Renseanlæg
	Helsingør Renseanlæg
	Sydkystens Renseanlæg
	Hillerød Renseanlæg
	Usserød Renseanlæg, Hørsholm
	Køge Renseanlæg
	Bjergmarken Renseanlæg, Roskilde
	Holbæk Renseanlæg
	Nykøbing Sjælland Renseanlæg
	Slagelse Renseanlæg
	Fakse Renseanlæg
	Stege Renseanlæg
	Næstved Renseanlæg
	Vordingborg Renseanlæg
	Nykøbing F. Renseanlæg
	Nyborg Renseanlæg
	Ejby Mølle Renseanlæg
	Middelfart Centralrenseanlæg
	Bov Renseanlæg, Padborg
	Gråsten Renseanlæg Huk
	Sønderborg Renseanlæg
	Aabenraa, Stegholt Renseanlæg
	Kolding Renseanlæg
	Fredericia Centralrensningsanlæg
	Vejle Centralrenseanlæg
	Horsens Centralrenseanlæg
	Grindsted Renseanlæg
	Esbjerg Vest Renseanlæg
	Esbjerg Øst Renseanlæg
	Ringkøbing Rensningsanlæg
	Herning Renseanlæg
	Søholt Renseanlæg, Silkeborg
	Marselisborg Renseværk
	Viby Renseanlæg, Århus
	Åby Renseanlæg, Århus
	Egå Renseanlæg, Århus
	Randers Centralrenseanlæg
	Mariagerfjord Renseanlæg

	Viborg Centralrenseanlæg i Bruunshåb
	Thisted Rensningsanlæg
	Løgstør Renseanlæg
	Ålborg Vest Renseanlæg
	Ålborg Øst Renseanlæg
	Hjørring Renseanlæg
	Frederikshavn Centralrenseanlæg
	Skagen Renseanlæg
Industrianlæg	CP Kelco ApS
	Nordic Sugar, Nykøbing Sukkerfabrik
	Nordic Sugar, Nakskov Sukkerfabrik
	Hvims Biogas, Nordjysk Minkfoder, Jørgen Johansen
	Bio Vækst A/S, Solum, Holbæk
	Novozymes A/S, Kalundborg
	Kalundborg Bioenergi
Lossepladsanlæg	Viborg, REVAS' Losseplads
	Hedeland Losseplads
	Grindsted, GEV Varme A/S
	Måde Losseplads
	Østdeponi Amba
	Sandholt Lyndelse Losseplads
	Biogasanlæg Højer, lossepladsgas
	Århus, Edslev, Kolt Kraftvarmeværk
	Randers, Verdo Produktion
	ESØ Deponigas A/S
	Vojens, Dybdal Losseplads
	Aunsøgaard, Svebølle-Viskinge Fjv.
	Odense, Stige Ø
	Affaldscenter Tandskov
	Kåstrup, MiljøSam gasanlæg
	Glatved Losseplads
	Korsør, Forlev miljøanlæg
	Aabenraa, Sdr. Hostrup Losseplads
	Ubberup Losseplads, Kalundborg
	Holsted, Affaldsselskabet Bobøl I/S
	Skodsbøl biogas
	Feltengård Biogas
	Gerringe Losseplads, Rødby
	Skibstrup Losseplads, Helsingør
	Ydernæs Losseplads, Næstved, AffaldPlus
	Fladså Losseplads, AffaldPlus
	Faxe Genbrugsplads, lossepladsgas
	Stengårdens Losseplads, Hvalsø
Fællesanlæg	V. Hjermitslev/Nordic Bioenergy v. Per Thostrup
	Vegger Energiselskab
	Herning Bioenergi, Sinding-Ørre Biogasanlæg

	Fangel Bioenergi
	Ribe Biogas A/S
	Linkogas, Tornumvej
	Lemvig Biogasanlæg A.M.B.A
	Hashøj Kraftvarmeforsyning A.m.b.a.
	Thorsø Miljø- & Biogasanlæg
	Bånlev Biogas (købt af Nature Energy medio 2019)
	Filskov Energiselskab
	Herning Bioenergi, Studsgård Biogasanlæg
	Blaabjerg Biogas
	Snertinge, Særslev, Føllenslev Energiselskab
	Blåhøj Energiselskab Amba
	NGS Nature Energy Vaarst
	Nysted Biogas
	Bornholms Bioenergi (tid. Biokraft)
	Limfjordens Bioenergi Aps (tidl. Morsø Bioenergi)
	Maabjerg Bioenergy, Maabjergværket
	Horsens Bioenergi, dr.leder Henrik Bie
	NGF Nature Energy Holsted
	NGF Nature Energy Midtfyn
	NGF Nature Energy Nordfyn
	Solrød Biogas, projektleder Mikkel Busck
	Sønderjysk Biogas Bevtoft, Marina Berndt
	Grøngas Vrå, GrønGas og E.ON Danmark
	NGF Nature Energy Månsson (økologisk)
	NGF Nature Energy Korskro
	NGF Nature Energy Videbæk
	Vinkel Bioenergi v. Skive
	GreenLab Skive Biogas, Kaastrup/Skive
	NGF Nature Energy Sønderborg (Glansager)
	Vesthimmerland Biogas, Holmevej, Farsø
	Naturbiogas Sode, Haderslev
	SBS Kliplev, Aabenraa
Gårdanlæg	Tovsgård Biogas, Jens Kirk, Skinnerup
	Houmarken, Gosmer Biogas Aps
	Rivendale Biogas, Ejnar Kirk, Hillerslev
	Fårborggård I/S, Claus Nielsen
	Nørreris Bioenergi, Bækagergård, Niels Kieldsen
	Østenfjeld Svineavl I/S, Nimtofte
	Nature Energy Hemmet, Hegndal
	Nature Energy Hemmet, Gundesbølvej
	Uhrenholtgaard, Morten Knudsgaard
	Tinggård, Andreas Østergaard
	Klitgaard, Ulsted Biogas Aps, Frank K. Johansen
	Badsbjerg, Ulsted Biogas Aps, Frank K. Johansen
	Rybjerg Biogas I/S, Jens Henry Christensen

Tågholm, Michael Sangild
Møllegården, Morten Kuhr
Lynggård Biogas Aps, Peder Andersen
Skive Biogas, Dølbygaard
Grøngas Hjørring, Jens Peter Lunden
O.L. Gårdbiogas (tidl. GFE Over Løjstrup)
Rønnovsholm, Aksel Kirketerp
Rønge, Carl Christian Bæk
Tumbøl Gårdbiogas, Claus Hissel
Hedegård, Præstevejen 7, Mesing, Mikael Munk Hansen
2 B biogas A/S, Ole Broholm Andersen
Baunsgaard Agro, Lihme
Pøl Biogas, Graugaard I/S, Henrik Clausen
Baverslund, Fastrup, Svend Åge Lyngby Pedersen
LBT Agro, Lars Bo Thomsen
GFE Krogenskær, Jan Ulrich
Kerteminde Biogas (tidl. Pilegårdens Biogasanlæg)
Forskningscenter Foulum
Gedsted Nørgård, Lundby Biogas
FS Bioenergi (tidl. Elmegaard Biogas)
Tandergård Biogas, Mårslet, Brian Munk
Holbæk Bioenergi I/S, Anders Rosenkvist
Madsen Bioenergi, Balling, Spøttrup
Hans Martin Westergaard, Kiplev/Aabenraa (økologisk)
Kroghsminde, Jens Krogh, vest for Ølgod (økologisk)
Viftrup Biogas, Knud Christensen, gas til Spjald KV
Kuhr-Hedegaard Biogas, Michael Kuhr
Zastrow Bioenergi, Steen Rasmussen
Frijsenborg Biogas, Frijsenborg Gods, Christian Ejby
Vrejlev Landbrug, Thomas Kjær, Vrå
Nature Energy Sdr. Vium
Vestergaard Bioenergi v. Sjoerd Ydema
Vestjysk Biogas, Borris, Ole Nyholm Knudsen
Ausumgaard, nord for Holstebro, Kristian Lundgaard-Karlshøj
Sindal Bioenergi, dr.leder Morten Glenthøj
BB-Biogas, Ålstrupvej, Vrå, Daniel O. Pedersen
Lykkeslund Bioenergi, Lars Langskov Nielsen, Otterup
Grønhøj Bioenergi, Thomas Jung Johansen, Karup
Storde Biogas, Bredebro, Jan og Niels Dahlmann
Iglsø Agro og Bioenergi v. Stoholm
LBJBIO, Vådagervej/Fuglebjerg, Bjørn Rasmussen (økologisk)
Nørgård Agro, Holstebro, Anders Nørgaard
Hærup Biogas v. Klejtrup/Hobro, John Jensen
Ringsted Biogas, Michael Mølgaard
Outrup Biogas, økologisk
KW Energi, Buskmosevej, Gråsten

Ølgod Bioenergi
Andekærgaard Biogas, Tåsinge
Birketvedgaard, ved Marslev nord for Langeskov
Kiddegård Biogas, Vejle, Henrik og Rikke Mols
Flemløse Biogas (Glamsbjerg)

C List of Biogas plants in Denmark

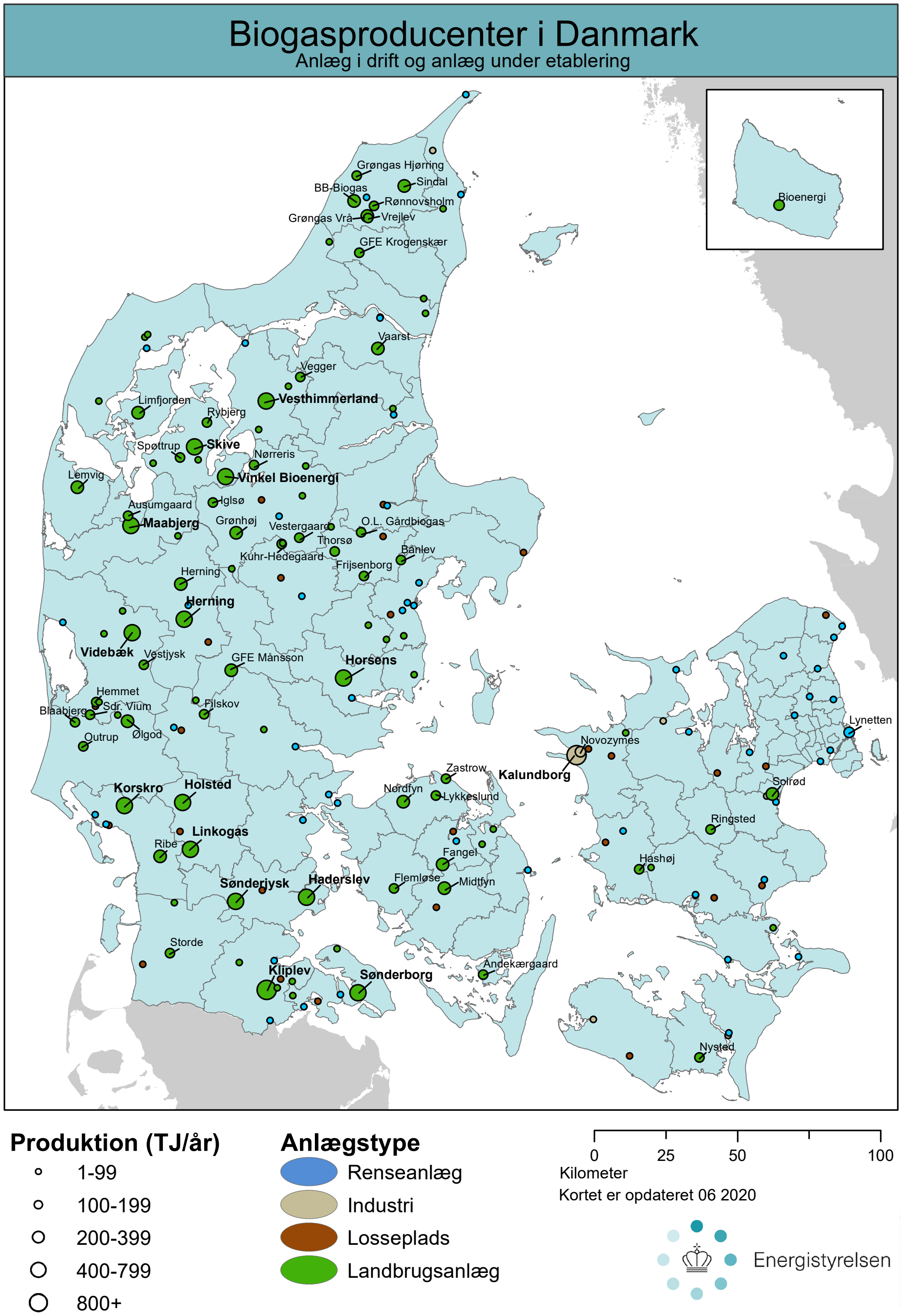

Figure 19: Map of biogas plants in Denmark as of June 2020 (The Danish Energy Agency, 2021)

D List of Biogas plants in Denmark

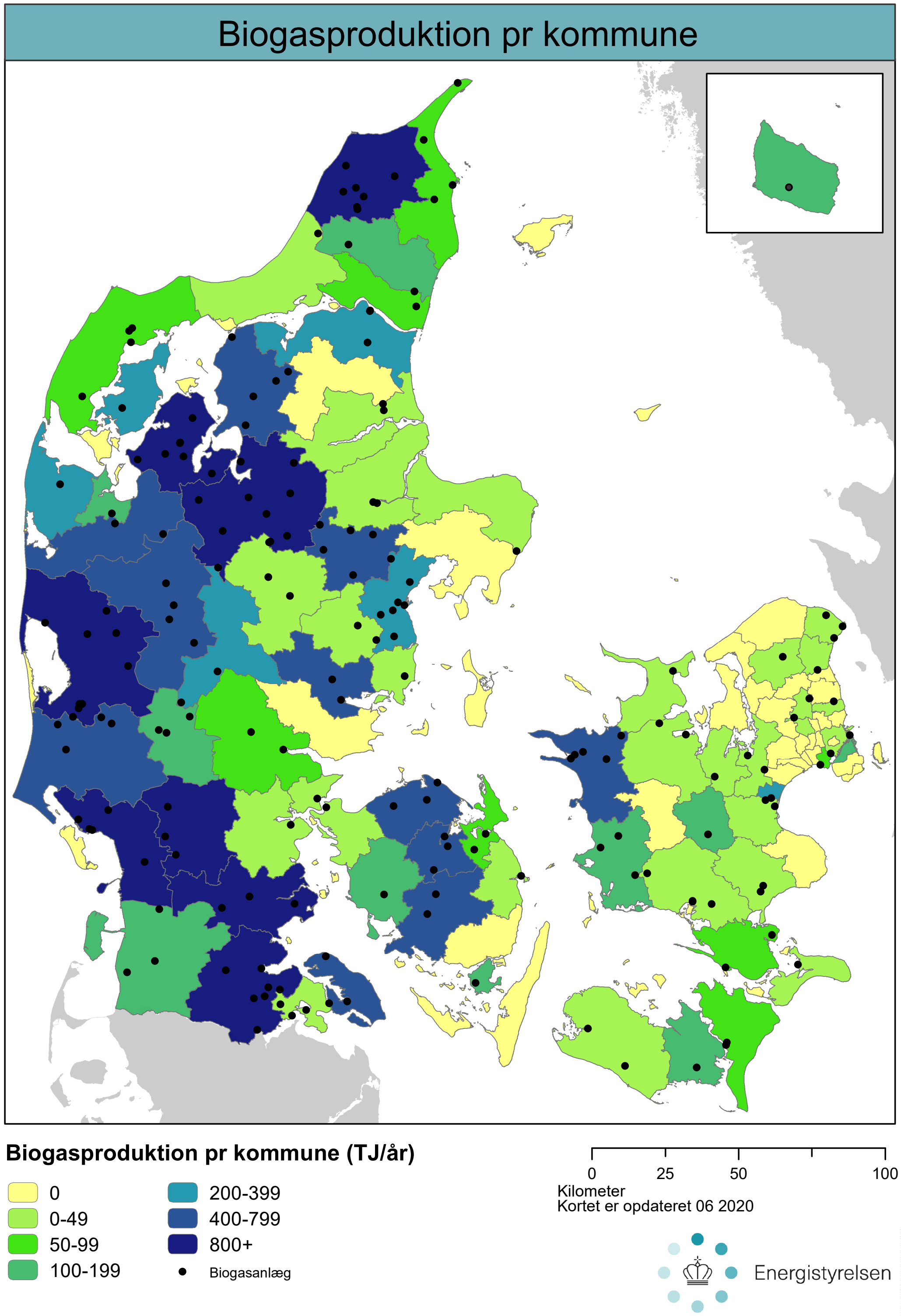

Figure 20: Map of biogas plants in Denmark as of June 2020 (The Danish Energy Agency, 2021)

E Development of Nitrogen emission from Danish fish farms

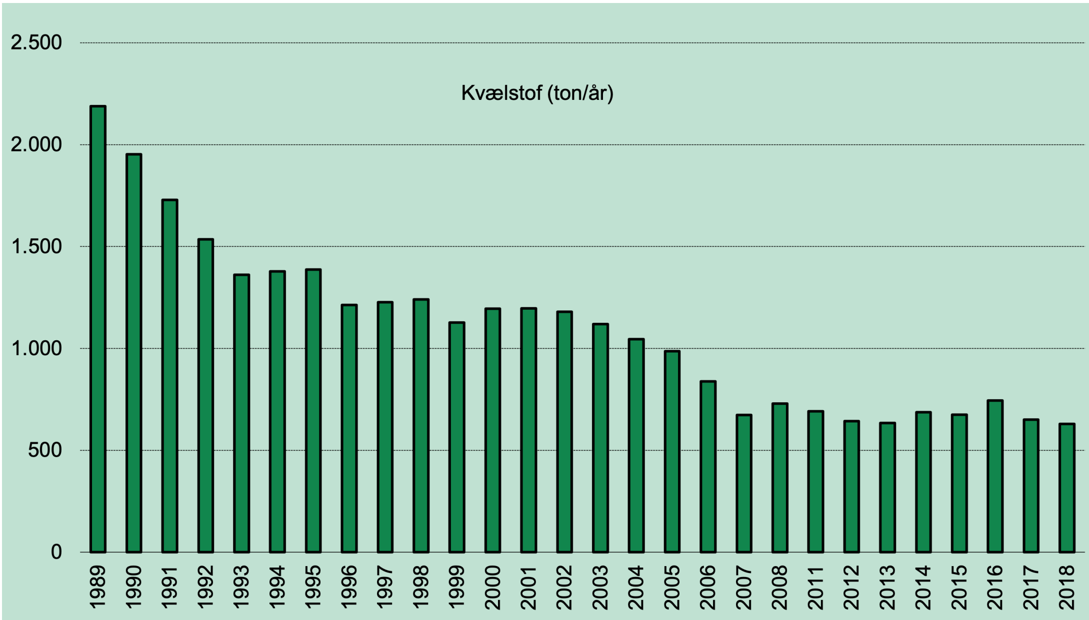

Figure 21: Total Nitrogen emission 1989-2021 (Ministry of the Environment & Food, 2019)

F Marked analysis

The following 17 pages is a section of the a previous written semester project written by the co-author K. K. Hansen (2021). The section is a market analysis of the fish farm industry. This is included to give the reader a better overview of how the marked is divided into the three segments and what specific differences is key to each of the segments. The literature list in the last pages is specifically for this market analysis.

6 Analysis

The analysis is structured to answer the problem statement and research questions, outlined in section 2. The analysis follow the methodology described in section 5.4.2. The development of a final value proposition, will in the analysis combine a number of different approaches, proposed in the literature review, section 4. The analysis consist of four main sections: (1) market analysis, (2) Identifying what create value, (3) adjustment of initial value proposition and (4) outline the final value proposition. Throughout the analysis are legal, customer based, financial and ecological implications taken into account.

6.1 Market analysis

This part of the analysis aim to clarify how the niche market of fresh water fish farming are segmented. As fish can be produced for many purposes and under different conditions, the specific value adding features might differ.

6.1.1 Market segmentation

As explained in the method section (5.4.1), the segmentation will follow a five step framework created by Huh and Singh [23].

Measurability

The measurability of the fresh water fish farms as a niche market is in Denmark generally divide into three main segments. These segments are determined by the production technology used. The three production technologies are (1) Traditional type, (2) Model type 1 and (3) Model type 3. It should be noted that there are a theoretical opportunity to create model type 2 fish farms, but none of these have ever been build in Denmark. Therefor, will no data from this segment be investigated in the following analysis. The overall data on the market is provided by Statistics Denmark[33]. Data available range from 2009 to either 2018 or 2019. The total numbers of fish farms are shown in table 5 below.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Traditional type	189	177	162	157	157	145	138	131	127	123
Model type 1	14	19	17	16	17	17	17	18	17	17
Model type 3	11	13	13	13	16	15	16	17	16	16

Table 5: Overview of the total number of active fish farms 2009-2018[33]

It can be seen that the number of active traditional fish farms has decreased close to 35% from 2009 to 2018. While both model type 1 and model type 3 has seen a slight increase in numbers in the same period. The reasons for the declining number of traditional fish farms is partly because of smaller fish farms are bought by the larger fish farms. This allow the larger fish farms to use the smaller fish farm's feed quotas. If the larger fish farm have access to more feed quotas, they can produce more fish. An other reason for declining number for traditional fish farms is that the small fish farms are legally permitted to report the same amount of water tests as lager fish farms and gradually make environmental improvements to the production system. This put the smaller fish farms under economical pressure.

But while the total number of fish farms has declined, has the total production increased from 2009 to 2019, see table 6. There are a clear trend of a shift from many smaller fish farms to fewer larger. Within all segments do we see increased average production pr. fish farm. This increase is particularly pronounced for model type 1 fish farms where the average fish farm in 2009 produced $68.6t/year$ and in 2018 produced $269.8t/year$.

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Traditional fish farm	15,285	14,821	14,425	16,474	15,513	15,925	15,213	14,511	15,110	13,322	13,364
Model type 1	961	1,506	2,667	2,967	3,119	3,086	3,853	3,747	4,293	4,586	5,166
Model type 3	4,317	6,423	7,001	7,620	9,025	8,198	9,373	8,996	8,769	8,737	12,389
Total	20,563	22,750	24,093	27,061	27,657	27,209	28,439	27,254	28,172	26,645	30,919

Table 6: Total production volume in ton pr. year, 2009-2019[33]

The increased production pr. fish farm is a result of a governmental push to shift from feed quota based production to emission based production. The feed quota is a permit to feed a given amount calculated specifically based on the size of the fish farm and the water flow, with a fixed standard for the ability to clean the water. This is specified in section 3.1.1. In the emission based production the feed quota is regulated after the measured emission of Nitrogen, Phosphorus and BOD. This means that the fish farmer can increase the yearly feed if the farmer invest in water cleaning technologies.

In regards to measurability, can it be concluded that the size of the segments can be clearly measured. As this industry is heavily regulated by the government, it is possible to pull data on the different segments directly from Statistics Denmark. Furthermore, is there a increasing focus on cleaning technologies within all segments. This focus stems partly from a governmental push, but is also supported by an economic incentive.

Substantiality

Substantiality will assess whether the segments are large and/or profitable enough. First thing to assess, is the overall value of each of the segments. This can be seen in table 7. The overall value of the three market segments have increased 82.7% from 2009 to 2019. Where the segment of model type 1 fish farms has seen the largest percentage increase of more than 630%.

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Traditional fish farm	323,673	301,196	319,891	340,510	328,005	370,713	380,109	356,858	393,588	346,102	343,321
Model type 1	16,812	31,410	53,566	56,375	60,684	64,402	86,011	85,208	100,184	108,928	122,770
Model type 3	67,081	110,567	133,166	97,257	170,231	168,962	207,591	196,508	196,156	194,211	278,611
Total	407,566	443,173	506,623	494,142	558,920	604,077	673,711	638,574	689,928	649,241	744,702

Table 7: Value of fish farms pr. year in 1,000DKK., 2009-2019[33]

The reason for the growth are closely connected to the increased production that is seen over the years. A decreased value and production can be seen in both 2016 and 2018. The main reason for this is the governmental initiated program to buy older low technological fish farms. It was part of the Finance Act from 2016 and still is. When the government buy a fish farm, the production is stopped and the feed quota owned by the fish farm will never be accessible for the industry again. Therefor will the total production decline.

When looking further into the general profitability of the three segments. The available data is calculated as an average pr. fish farm, see table 8. For both the traditional type and model type 1 fish farms, the profit margin has varied throughout the years. This is an indicator that the fish farms have had a hard time creating profit some years. Though the traditional fish farms has been more profitable from 2014 and forward. The increase in profit for traditional fish farms might be connected with the governmental acquisition of low performing older fish farms. The model type 3 fish farms show a stable positive profit margin every year since the finance crisis while increasing production.

	2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Traditional fish farm										
Population, total	189	177	162	157	157	145	138	131	127	123
Profit margin %	- 2.1	0.6	3.0	3.1	- 0.4	3.3	5.3	6.5	7.5	4.3
Rate of return %	- 1.4	0.4	2.6	2.6	- 0.3	2.7	4.5	6.4	7.0	4.5
Solidity (Equity Ratio) %	17.2	19.5	21.1	26.8	27.5	22.7	28.2	23.6	28.2	10.6
Gross yield (1,000DKK.)	2,523	2,140	2,436	2,724	2,456	3,032	3,260	3,304	3,654	3,929
Model type 1										
Population, total	14	19	17	16	17	17	17	18	17	17
Profit margin %	- 0.2	4.4	2.8	0.6	- 1.3	3.1	-	- 0.1	8.1	5.8
Rate of return %	- 0.2	3.7	2.0	0.5	- 1.0	2.6	-	- 0.1	6.7	5.2
Solidity (Equity Ratio) %	16.3	18.2	15.6	17.3	16.3	18.0	14.6	7.1	15.0	12.1
Gross yield (1,000DKK.)	3,276	3,895	4,887	5,535	5,622	6,214	6,833	5,940	7,012	7,129
Model type 3										
Population, total	11	13	13	13	16	15	16	17	16	16
Profit margin %	6.1	7.9	4.7	10.6	2.0	6.4	7.9	5.5	2.9	1.4
Rate of return %	3.6	4.8	3.4	8.9	1.8	6.4	7.3	5.4	2.3	1.2
Solidity (Equity Ratio) %	12.5	16.3	19.1	19.0	15.2	15.4	17.6	14.9	10.9	16.1
Gross yield (1,000DKK.)	8,408	10,945	12,288	9,573	11,457	12,496	14,353	14,390	14,482	14,408

Table 8: Overview of average profitability of fresh water fish farms[33] 2009-2018

The rate of return could indicate that the investment made in both the traditional type and model type 1 fish farms are hard to return profitable. At the same time has the model type 3 fish farms provided stable positive return rates on the investments.

Throughout all three segments, are the equity ration rather low. This might suggest that the owners of fish farms has paid for a rather high percentage of the assets through bank loan. Conversations with Peter Holm, has reviled that the financial valuation of the assets at a fish farm is very low. An example of this, can be seen when a fish farmer establish the plant lagoon. This is effectively "just" a hole in the ground filled with water. From a banks perspective is it hard to assign this investment a high valuation as the resale value for a lagoon is low compared to production equipment in other industries. Thereby, will both the equity ratio but also the rate of return effectively be lower.

Lastly is the the gross yield assessed. This number gives insight in how much value the production create after fixed cost of production. This also means that the variable cost of the traditional and model type 1 fish farms are higher than the value created in the production in some years. Model type 3 fish farms has a significantly higher gross yield than the two other segments. At the same time do this segment manage to keep variable costs low enough to produce a positive profit margin. The higher average gross yield also correlate with the higher production volume in this segment.

In conclusion is the profitability of each segment different from each other. Where the traditional fish farms has struggled in both 2009 and 2013 is the tendency that this segment are performing better on an average. The model type 1 fish farm show fluctuating results and has at this state not been stably profitable for more than the past two years. The model type 3 is overall profitable every year with a somehow stable result per year. This show that the segment of the most advanced fish farms could have the strongest economical capabilities as a customer.

Differentiability

Differentiability can be assessed by investigating the general production method and layout within the three segments. In the following will the key characteristics that make the three different segments different from each other.

The traditional fish farm is from a technological perspective the least advanced. The following description is based on on-site observations and interviews. Figure 11 is a flow chard, showing the process steps in a traditional fish farm. In order for the fish farm to reduce cost is 100% of the water used in a traditional fish farm from nearby streams. Legally the fish farms are permitted to recover no more than 50% of the median minimum water flow in the water stream[2]. The natural flow of the stream is utilized to bring the water through a feeding channel from the water stream to the fish pools. In the fish pool is the core production. The fish pools are typically constructed of earth walls. This type of production will normally have a fish density of fish is often between 5 and $15kg/m^3$ The following process steps are included to reduce nutrient levels in the water, as well as the BOD level. As the water flows out of the fish pool, the solid waste from fish, is separated from the water in the sludge cones. The solid wast is transported to a slurry pit that will be emptied by an external company. Excess water from the slurry pit contains high concentrations of nutrients. The excess water will flow to a slurry lagoon. This step will ensure further settlement of solid waste. Lastly will water from the slurry lagoon flow further into the lagoon area.

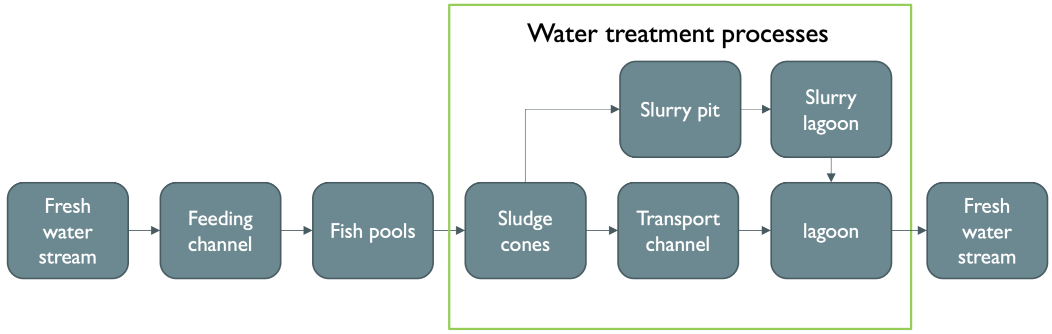

Figure 11: Process flow of a traditional fish farm

The primary water flow will go through a transport channel to the lagoon. The lagoon is a large area, often divided into a number of smaller section where the water gradually flow through. The total surface area of the lagoons depends on the size of the fish production. As seen in the flow chard will non of the water return into the fish farm again, but flow out into the stream. This type of system is called a flow through system. Traditional fish farms have to meet the regulations on maximum feeding quota as well as the maximum emission levels of Nitrogen, Phosphorus and BOD.

When a fish farmer upgrade to or build a model type 1 fish farm there are three main areas of difference. The model type 1 are recirculating the water within the production system at a degree of 75%. This reduce the water consumption but increase the power consumption because of water pumps. The second difference from the traditional fish farm is that the fish density in the fish pools is higher, at 10 to $50kg/m^3$. The last difference is an increased focus on water treatment to remove nitrogen, phosphorus and BOD from the water.

Figure 12 is the flow chard of a typical model type 1 fish farm. It can be seen that the first part of the flow chard is similar to the one of the traditional fish farm. But after the sludge cones is a number of micro screens (mesh) placed. These screen will remove even more of the biological mass from the water because of the 74μ screens, and move the solid waste to the slurry pit. This enables for the high degree of re-circulation, that is required in order for the fish farm to reach the status of model type 1. When the water reach the transport channel will 75% of the water be returned to the feeding channel. The following steps in the flow chard is conceptually similar to the traditional fish farm.

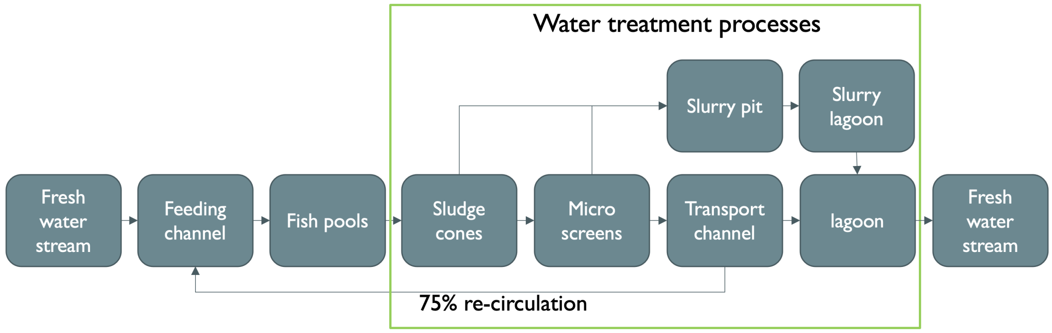

Figure 12: Process flow of model type 1 fish farm

The segment of model type 3 fish farms is again a step up in regards to the production technology. In this segment is the re-circulation degree increased to minimum of 97%, see figure 13. That makes this segment the most water efficient, but at the same time the segment with highest power consumption. The water used for this segment need to be as clean as possible, and will therefore only use groundwater that is pumped up directly at the location.

Besides the regular fish pool can it be seen that the model type 3 segment use Raceways. This type of pool is strictly speaking also a fish pool, but with increased focus on oxygenation of the water due to the fish density. The general fish density in this segment is $40kg/m^3$ and above. Compared to the two previous mentioned segments, does this segment have a significantly larger production[4]. Therefor does this type of production have the largest focus on water treatment.

As the water run through the sludge cones, micro screens and the transport channel, will the water be treated in a bio-filter. The bio-filter is a specialized water treatment element that promote the nitrification process[5] as well as reducing the BOD level of the water. From the bio-filter will the water flow to the lagoon. The size of the lagoon need to be large enough to reduce the nutrient level to the permitted level.

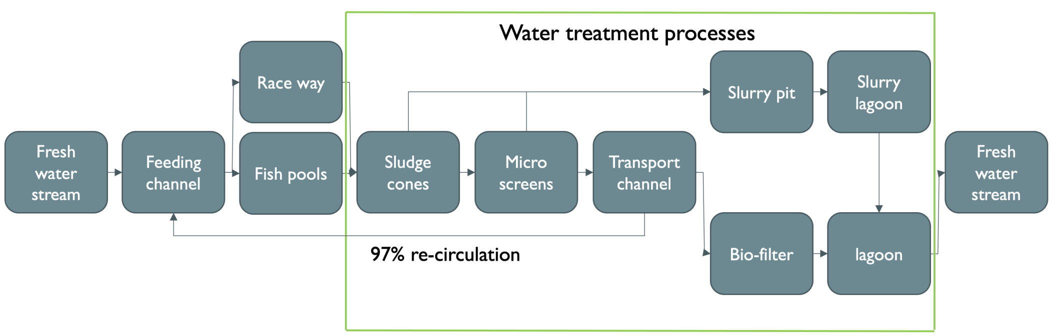

Figure 13: Process flow of model type 3 fish farm

[4]Avg. fish production in 2018: Tradition fish farm: 108.6t/fish farm. Model type 1: 269.8t/-fish farm. Model type 3: 546t/fish farm[33]

[5]Nitrification is the process that converts ammonia to nitrite and then to nitrate

In conclusion does the three segments differ mostly in the size of the production and will therefore need to specialize in water treatment at different levels. But the water treatment is a core component in all three segments.

Accessibility

The three segment's accessibility are assessed from the perspective how easy it can be to reach the customer. From a geographical perspective will this assessment focus on the Danish fish farms. In Denmark is almost all of the fish farms located in the western part. In figure 14 page 32, is an overview of the location of all active fish farms in Denmark. It should be noted that all off-shore fish farms use salt-water, and will therefore not be included in this study. Because all fresh water fish farms of the three segments are located relatively close to each other, the accessibility is high from a geographical perspective.

Beside the location will the available space on each fish farm have an influence on the accessibility. Because the value proposition developed in this study might allocate some unused space at the fish farm. But it have not been possible to assess available space on the fish farms in the three segments to a point where a general conclusion can be drawn. At the visited fish farm owned by Peter Holm, could it be seen that there were available space that Peter was willing to give up to further water treatment, if the production could be increased.

In conclusion will one segment not be either harder or easier to approach as customer from the perspective of accessibility.

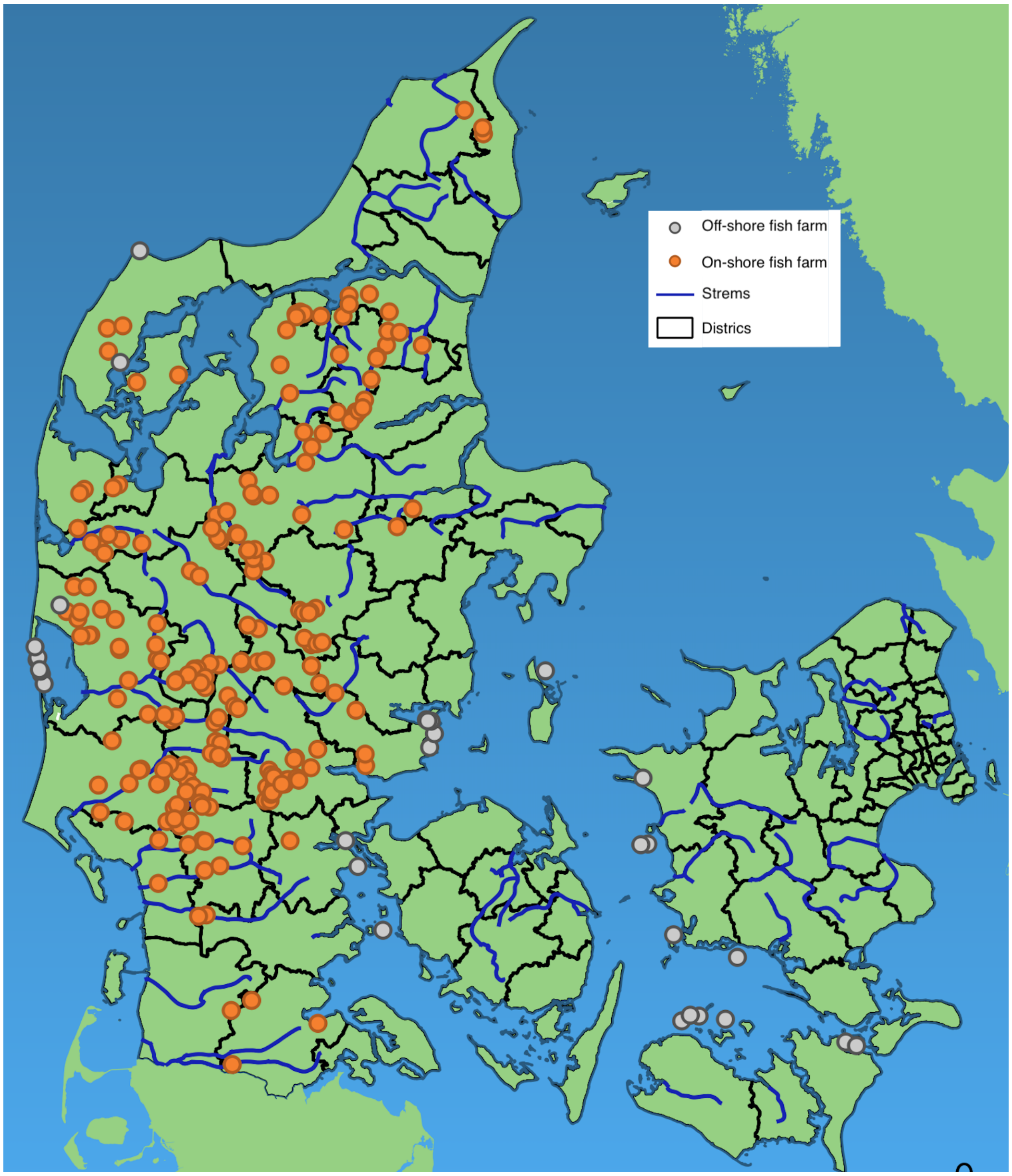

Figure 14: Overview of locations of fish farms in Denmark[34]

Actionability

All three segments in this analysis are guided by the governmental legislation imposed. This gives a large amount of insight in the requirement that the fish farms in each segments strive to meet both in the construction phase and when optimizing the water treatment system. These requirement are the basis of the flow charts in figure 11, 12 and 13.

In order for a traditional fish farm to operate, it need a environmental approval. This production allowance approval can be measured in one of the two following methods. The old way is the "Feed quota" method. The specific calculation is outlined in equation 3.1.1 page 5. In practice will the size of the intake stream determine the size of the fish farm and the legal maximum for fish food used on a yearly basis. At the same time will this type of environmental approval also dictate the amount of water treatment techniques, based on the size of the feed quota. Naturally, will this method give all traditional fish farms a physical limit for the maximum production size. The majority of the traditional fish farms still use this old type of environmental approval. This is also the reason why the average production size in this segment the lowest of the three segments.

The newer type of environmental approval, is the "emission based". This type of approval was legally introduced to the industry in 2016[2] to increase productivity of the Danish fish farms. With this type of approval is the fish farmer permitted to test the nutrient level of the excess water from the fish farm 26 times a year. This will is to prove that the nutrient level at no time exceeds the expected levels. The expected nutrient emission levels are the same as they would be with the feed quota method, but the fish farm can increase the fish production as long as the water treatment is increased proportionally. The local counsel will assess the water measurements at the fish farm and give the permission to expand the business as long as the nutrient emission is kept below the legal limit.

The government of Denmark is trying to make as many of the fish farmers move to the emission based approval. By allowing for growth in this industry, will it create work in the local districts and increase the total export. In the interview with Peter Holm, did he explain that the interest organization of Danish fish farmers expected a potential of up to 300% increase in production for a traditional fish farm, shifting from feed quota to emission based approval.

The smaller segments, model type 1 and 3 fish farms, are already permitted to use increased amount of water treatment, but can still make improvements in the production system to shift to the emission based environmental approval. Peter Holm said that he expected a growth in model type 1 and 3 in the years to come with the reason being: "If a traditional fish farm want to invest in the necessary water treatment to shift to emission based approval, the fish farmer will most likely make the extra investment to shift to a model type fish farm." Peter Holm had in November received the approval to make this exact upgrade from a traditional fish farm with feed quota approval to a model type 1 fish farm with emission based approval.

The actionability of the three segments show in conclusion that the actions are heavily driven by governmental regulations. The latest emission based environmental approval has opened the opportunity for growth within all segments. But while it is possible for traditional fish farms to make the shift to this type of approval, it is highly likely that the traditional fish farms, will change to the segment of model type fish farms.

6.1.2 Conclusion of the market

The niche market of fish farms can be divided into three segments. With the segment of traditional type being the largest both in number of fish farms and total production size. This segment has had a number of years with lacking economic performance but has shown an increase in economic growth since 2014 and forward. The processes used are usually utilizing the lowest possible energy and technology to reduce cost. Due to governmental actions is this segment forced to optimize the production system and might switch to a different segment in the future.

The segment of model type 1 fish farms in Denmark has seen a production increase of more than 430% from 2009 to 2018 while only increasing from 14 to 17 fish farms in the same period. Despite the large growth in production volume has this segment seen unstable profit margins and multiple years with without profit at all. The water treatment processes in this segment is well suited for a transition to emission based environmental approval and will will therefore see an increase in number of fish farms in this segment.

The model type 3 segment is the most technological advanced, and will have the highest cost of investment. The production volume pr fish farm is the highest due to the layout. From a financial perspective is this the most consistent performing segment. The overall production in this segment is estimated to grow in the years to come as the market adapt to the latest executive order for fish farms.

In conclusion are all segment within the market of fresh water fish farming expected to have a continuous focus on increased water treatment. Especially the segment of traditional fish farms are expected to invest in the market of water treatment technologies. The effect will be that this segment will continue to decline in numbers. Model type 1 fish farms are the segment where most of the traditional fish farms will move to, due to the low cost of entry. For this reason are the two segments of traditional and model type 1 fish farms the most appealing, as these segments are forced to invest in the future, in order for the farms to stay in business. Although all three segments share the same interest for water treatment, will these two segments most likely be the most interesting to focus on. To help customers in the traditional fish farm segment excel to the model type 1 segment including the shift to emission based production. Furthermore, to help existing model type 1 fish farms shift to emission based environmental approval.

6.2 Identifying what create value

In this section are the core value adding features of the fish production assessed. After this assessment are a number of assumption outlined and prioritized. Followed by a presentation of an initial value proposition, based on the market analysis and assumptions.

This assessment follow the approach described in section 4.4 by John Krupczak[30]. First step is to identify the system boundaries. In the Market segmentation has the systems functional process steps in the a fish farm been defined. The boundaries of interest are the water treatment elements. This is when the water exit the fish pool and until it move out into the stream again. The developed value proposition need fit together with the water treatment elements, that are required from a legal perspective.

Next are the overall function and flows assessed. This is done step by step and will take reference in figure 11 and 12 in section 6.1.1. Figure 15 below, show an overview of the processes in the water treatment processes in a model type 1 fish farm.

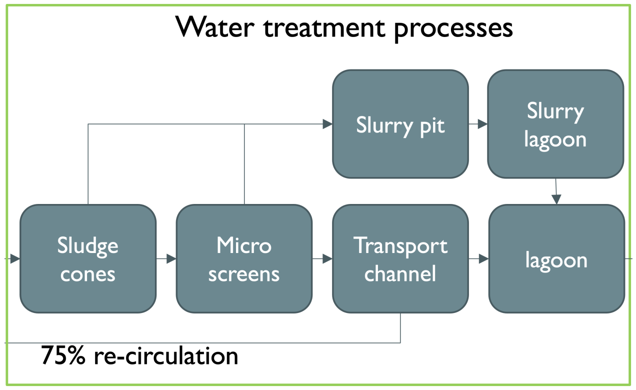

Figure 15: Water treatment processes of a model type 1 fish farm

Sludge cones are necessary to remove solid waste from the water. The solid waste consist mainly of fish excrement, fish food and plant material. All the water from the fish production will flow through this step. The solid waste is rinsed out of the sludge cones with water pressure coming from the fish pool.

The Micro screens are used as an extra step to remove small elements of solid waste, that is not caught in the sludge cones. This fine mesh can be design both as as cylinder or a number of flat panels. The filtered water will mover further in the system and the solid wast will be moved to the slurry pit.

The Slurry pit receive all solid waste from the sludge cone and the micro screens but the solid waste is mixed with water. Therefore, is the slurry pit design so the solid wast will sediment over timer. The content of the slurry pit is rich with nutrients. This is emptied on a regular basis and used as fertilizer on fields. Because the solid waste is mixed with water will the slurry pit have an overflow outlet.

The Slurry lagoon receive the outlet water from the slurry pit. This water is still very rich in nutrients. The objective is to let the last of the solid waste sediment and create a low oxygen environment to boost the denitrification processes. In this process will Nitrate (NO_3^-) and Nitrite (NO_2^-) be converted to Nitrous (N_2O). The Nitrous will gasify slowly. Thereby is the total Nitrogen level in the water reduced. The drawback with this process is that Nitrous is a very potent greenhouse gas, about 300 times stronger than carbon-dioxide. As the slurry lagoon is filled, will an overflow outlet lead the water to the last process step in the water treatment system.

The lagoon receive water from both the transport channel and the slurry lagoon. The water from these input sources have too high nutrient and BOD levels. In the lagoon will further denitrification reaction reduce the nitrogen level. The size of the lagoon is determined by the water flow and feed level in the production system. The reason for this, is that the water need a resident time in the lagoon between 12 and 36 hours. In this time will the phosphorus and small elements of solid waste sediment. Usually will plants grow in and around the lagoon. Through the plants growth is the level of both Nitrogen and phosphorus be reduced.

Next are the core technologies in the system identified. In order for the water treatment to remove nutrients and biomass (solid wast), will these process steps utilize sedimentation and/or the natural biochemical process of denitrification.

The processes of sedimentation is a remedy utilized within all steps of the water treatment. The sedimentation has an direct impact on the BOD and Phosphorus levels in the water. The sedimentation process require the fish farmer to manage and remove the material. The removed materials from the slurry pit have two main use cases. First and least costly, is an agreement with a bio-gas plant. For a 100t fish production will the typical cost of removal of solid wast be 10.000DKK. a year. If this is not possible, can local farmers use the solid wast as fertilizer on the fields. In this case will the fish farmer typically pay about 30.000DKK. for a company to spread out the solid waste on the fields. The yearly cost of managing the sediments from the lagoon will typically be around 50.000DKK. pr year. This price cover a hired person with an excavator to remove sediments from all the lagoon area.

The second fundamental part of the water treatment process, is the bio-chemical denitrification process. This process require an environment of low oxygen. The nature of the denitrification process is boosted in areas with sedimentation. In that way does the two water treatment processes work together. An additional bio-chemical processes helping in the environment of low Oxygen, is the creation of Methane gas. Through this gasification process is some of the bio-materials from the solid wast removed. The gasification help the fish farmer reduce the liquid emission levels, but have a larger impact on the general environment. This is because both Nitrous and Methane gas is very potent greenhouse gasses. However, the emission of these gasses are not measured and restricted from a legal perspective.

This next part of the analysis will cover the different water treatment processes and arrange them by looking at the performance and cost. The general perspective is the cost per ton feed as the input of the system. This is an calculation that is standard in the executive order for fish farms in Denmark[2]. The water treatment processes are scaled to fit the production volume of the fish farm. In table 9, are the minimum requirements of a feed quota based emission approval fish farm with a yearly production of 100ton calculated as a reference.

Standard production emission	**Kilo pr. ton feed**	**Degree of purification (%) 100ton production**	**Kilo cleaning pr. 100t production**
Ammonium-nitrogen	39	55	1930.5
Total nitrogen	56	50	2520
Total phosphorus	4.9	65	286.7
BOD	97	75	6547.5

Table 9: Water treatment yearly responsibility[2]

It should be mentioned that the total volume and mass of removed waste by the water treatment processes is very hard to estimate. The reason for this, is that the mass removed from the Slurry pit and Lagoon can have vastly different water content, which effect the weight. Furthermore, is the nutritional content different throughout the year. Lastly is the yearly gasification not measured and thereby not quantified.

As mentioned, are the numbers shown in table 9 calculated for a feed quota based fish farm. It is therefor clear that the task to clean nutrient and BOD from water is proportional larger in a emission based approval fish farm, partly because the fish production is larger, but also in cases where the production exceeds 230ton pr year. When the production exceeds 230ton pr year, are the restriction on degrees of purification is higher.

Lastly, will this part of the analysis show the cost of each of the water treatment components of a model type 1 fish farm. The calculated prices of investment and running cost, are bases on interview with Peter Holm, see table 10.

Water cleaning processes (100t)	Cost of investment	Operating costs
Sludge cones	160,000	30,000
Slurry pit	240,000	50,000
Slurry lagoon	60,000	10,000
Micro screens	400,000	20,000
Lagoon	600,000	50,000
Total	1,460,000	160,000

Table 10: Water treatment cost of investment and operations

The cost of investment shown in table 10 reflect a newly created fish farm. The cost of investment will be lower for a traditional fish farm transitioning to a model type 1 fish farm.

To give an overview of the layout, a model type 1 fish farm is this shown in figure 16 page 38. The production size of this fish farm would be have a standing population of 40 ton, and a yearly production of 100 ton. This representation of a model type 1 fish farm has an estimated area of 21,000m^2. Of this total area does the fish pools cover approximately 4,000m^2 (19%).

In conclusion is value creation in the fish production on all types of fish farms limited to the ability to clean the water from Nitrogen, Phosphorus and BOD. The general processes and layout of water treatment processes in fish farms take up the vast majority of the available space. The two core methods for water treatment is sedimentation that can be removed physically and gasification of Nitrous and Methane. These fundamental water treatment elements are split up into five process steps that either utilize one ore both elements. The water treatment steps has a total cost of investment at close to 1.5mio DKK. and yearly operation cost of 160,000DKK.

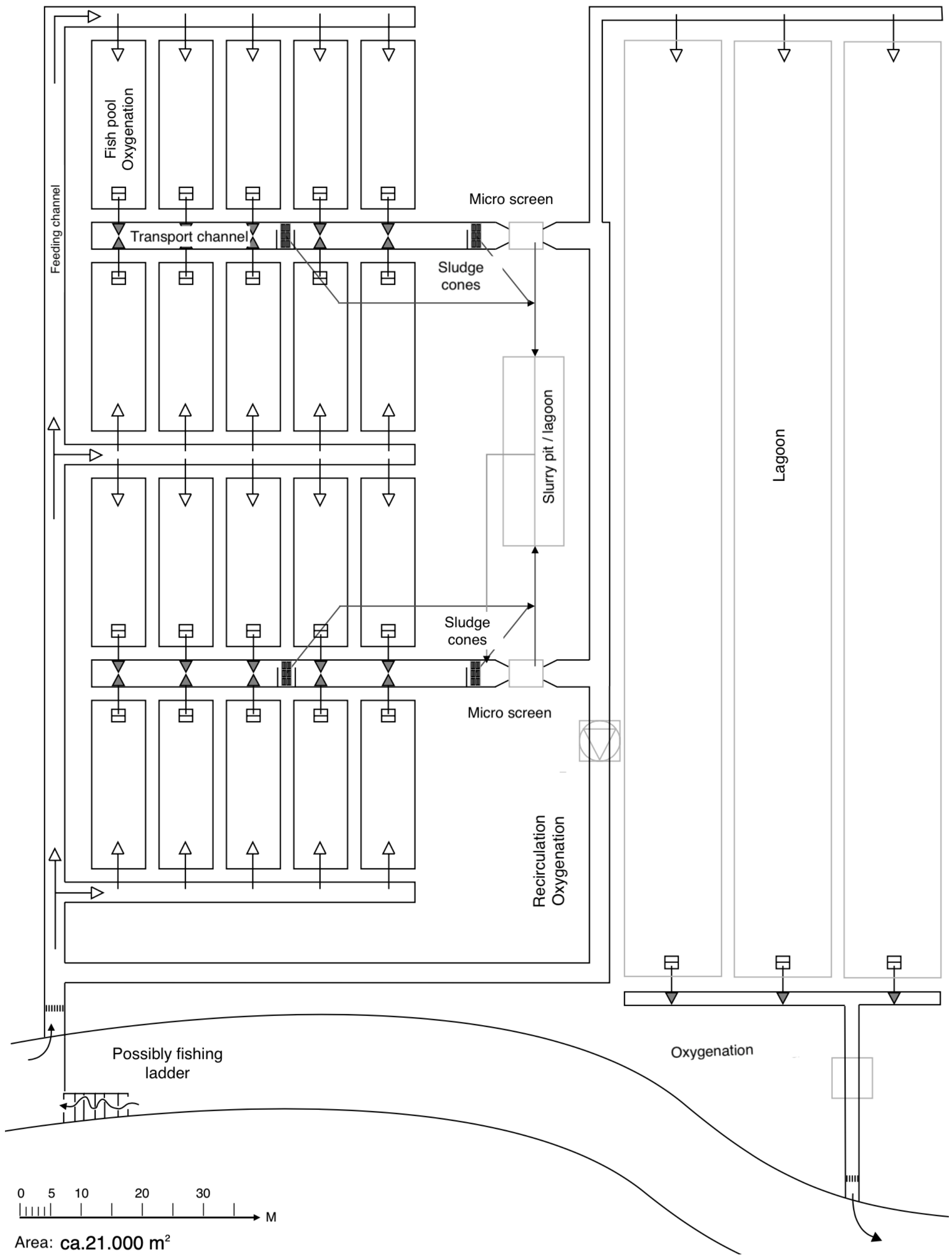

Figure 16: Layout of model type 1 fish farm[4]