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Mapping of regional bioeconomy opportunities

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Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, and the Faroe Islands, Greenland, and Åland.

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Preface

This report is a summary of discussions and written contributions from a group of scientists and experts from different fields. The coordination and editing of the work has been carried out by Agro Business Park in close cooperation with the report contributors. Each partner has been asked to contribute with written material (a section/chapter for the report) within their specific field of expertise. This material was presented and discussed at two workshops and a public seminar. Finally, the oral and written contributions have been edited and merged into the present report.

The consortium consisted of Nordregio (Sweden), Swedish University of Agricultural Sciences (Sweden), Latvian Farmers parliament (Latvia), Maritime Institute in Gdansk (Poland), Matis Ltd (Iceland), and four Danish partners, namely University of Copenhagen, Aarhus University, AgroTech Holeby, (formerly Green Center) and Agro Business Park.

The work intends to create a foundation for further studies and contributions to the bio-economical challenges of replacing imported and unsustainably produced soy products with locally and sustainably produced protein sources. This will involve a substantial change in livestock and fish production, which requires technological innovation and extensive studies. This report aims to outline the next steps required.

Summary and Recommendations

There is an increasing demand for dairy and meat products on the global market. In the Nordic and Baltic Sea Region, there is already a considerable production of these products, which is expected to increase. At present, the production of dairy and meat products relies on large quantities of imported protein rich feed in the form of soy products from South America. The production of soy in South America is considered by many organisations, however, to be unsustainable.

This presents both a challenge and an opportunity for a future local and sustainable production of protein rich feed in the Nordic and Baltic Sea Region. Several alternative ways of producing protein rich feed has been identified using regional resources and new opportunities within agriculture, forestry and marine/aquatic production systems.

Within the agricultural sector, there are possibilities to expand local production of legumes, pulses and grass. New and alternative protein rich sources in other sectors include single cell protein (SCP), macroalgae (seaweed), mussels and insects.

As the quest to find sustainable ways of producing protein rich food stems from the consideration that South American soybean production is unsustainable, local production of protein rich feed will need to be evaluated in terms of environmental impact using Life Cycle Assessment methods. At present, there are no studies that have used the same methodologies or systematic approach to compare the environmental impact of the production of the various alternative protein sources. It is, therefore, not currently possible to favour/recommend one or more of these over and above the others.

The current case study clearly shows that it is possible to increase the production of protein rich feed in the Nordic and Baltic Sea Region for animal and fish feed. Local production may also result in a number of additional benefits in the form of preservation or generation of local jobs, reduction in the import of nutrients and in general boosting the bioeconomy.

Many of the alternative ways of producing protein rich feed are still under development and there are many uncertainties with regard to production costs, environmental impact and the final feed quality. Furthermore, several barriers have been identified. The consortium behind this report, therefore, presents the following general recommendations:

- Much more focus should be directed towards this emerging field of local protein sources and production in terms of interdisciplinary research in close cooperation with the interested private companies (industrial or SME's). This applies to all the fields represented in this report.
- Thorough economic feasibility studies on the production of alternative protein sources should be carried out.
- More LCA studies on alternative protein sources should be performed when the technologies become more mature since at present only data exist on non-optimized systems. Furthermore, there is a need to develop better methods to take into account differences in indirect land use impacts as well as the impact of nutrient recovery from marine areas.
- A detailed analysis should be conducted of the feasibility and legislative barriers for these new alternative protein sources to be used for feed.
- Studies should be conducted on the potentials to differentiate (taste, texture) the meat, milk and egg products using different alternative protein sources, including consumer perspectives.
- Demonstration and investment projects should be conducted to test and scale up the most promising relevant technologies in the Nordic/Baltic Sea Region regarding the production of protein rich feed.

More detailed recommendations are found in relevant chapters of this report.

1. Introduction

The Nordic and Baltic Sea Region have a high production of meat and dairy products and compete on an international market with increasing demands. The local natural preconditions and traditions for agri- and aquaculture vary greatly from Iceland to Latvia or from Poland to Norway, and there are several regions, which produce intensively, especially for salmon, chicken, pig and dairy products.

Common for the production of meat and dairy products, is the need for feed with high quality protein. Currently, the Nordic and Baltic Sea Region has a net import of protein feed, which is primarily in the form of soy.

On a worldwide scale soybean meal and fishmeal are the two main sources of protein in livestock diets and there are continued efforts to increase fish production using soy beans (see e.g. http://www.soyaqua.org or http://www.soyaquaalliance.com). One of the major concerns related to the import of soybeans and soybean meal to the livestock sector in Europe, is the environmental issues associated with soybean production, especially in South America, which is considered unsustainable by many interest groups and policy makers. This work summarises existing relevant Life Cycle Assessment studies. Another concern is the massive dependency on import of protein crops that makes the EU livestock sector vulnerable to price volatility and trade distortion (De Boer *et al.* 2014).

Intensifying livestock and fish production results in a concomitant concentration of nutrients and this issue has to be dealt with in order to avoid local/regional pollution of air and waters. Many studies have focused on the environmental aspects of livestock production and much political regulation has had this focus (Nitrates Directive, Emission Ceilings Directive, Water Framework Directive etc.) (e.g. HELCOM 2010).

In addition to global environmental issues and a steady protein supply, local production of protein feed could also benefit many sectors in the form of preservation and generation of local and regional job opportunities.

1.1 Protein Replacement – A Bioeconomical Challenge

Bioeconomy is increasingly high on the political agenda and can be defined in different ways. Bioeconomy is in this context understood as a sustainable production and use of biological resources and their potential conversion into pharmaceuticals, food, feed, bio-based products and bioenergy via innovative and efficient technologies. Bioeconomy is often associated with advanced biorefinery concepts and in this report, we focus on the production and refinement of proteins for feedstock from a variety of biomass resources and on the environmental consequences of harvesting/refining/using it for livestock production.

A broad mapping of Baltic Sea Region bioeconomy stakeholders and opportunities was presented by the Nordic Council of Ministers in March 2014 (Winther & Klarlund, 2014). This was a product of the NCM project "Ten Steps to Realize the Bioeconomy in the Baltic Sea Region" that has been initiated as part of the "Horizontal Action for Sustainable Development and Bioeconomy in the EU Strategy for the Baltic Sea Region".

Nordic Prime Ministers and Council of Ministers for Fisheries and Aquaculture, Agriculture, Food and Forestry see bioeconomy as potential local rural development in a globalised world. In 2014 the Icelandic chairmanship launched a bioeconomy program – NordBio – to strengthen the Nordic countries innovation in relation to the bioeconomy in EU and the global bioeconomy in general.

Within agri- and aquaculture, a specific bioeconomy challenge – and a bioeconomy opportunity – has been identified concerning protein supply for livestock production and fish farming. The total EU protein crop production (e.g. legumes, soybeans) currently occupies only 3% of EU's arable land (Euractiv, 2011). In 2012, 34 million tons of soybeans and soybean cakes, equivalent to 15.5 million tons of protein, were imported into the EU. These protein sources mainly originated from South America. In terms of land use abroad, these imports represent 10% (20 million ha) of EU's arable land (De Boer *et al.* 2014). There is thus a large potential/demand for local protein production. The European Parliament adopted a resolution on "The EU protein deficit: what solution for a long-standing problem?" in 2011, putting forward a series of potential measures to reduce the dependency on imports of protein crops for animal feed, primarily from the US, Argentina, and Brazil (Euractiv, 2011).

The global demand for proteins is expected to increase as a measurable consequence of ongoing growth in the world population. If nothing is done, the growing demand will lead to increased prices, putting pressure on animal production and ultimately also on food security. However, there are alternatives to protein rich soy products. This report aims to identify alternative protein potentials and point out the socio-economic, environmental and animal welfare challenges in addressing these potentials.

Many environmentalists would argue that the soy replacement challenge could be solved by reducing animal protein consumption. This report, however, does not enter the discussion of the level of meat, egg and dairy products that should be produced or consumed on a global or Nordic/BSR regional scale. In the project, the basic assumption has been that the level of livestock and fish production is market driven due to the global demand for meat and fish products – and that this level can become more sustainable through optimal utilisation of the local resources. Thus, we do not attempt to promote a reduction in meat consumption or radical changes in the present agri- and aquacultural production system; rather we indicate where new innovations are needed to improve or expand the present protein production systems. We explore activities, technologies and new developments that have the potential to minimise/reduce the need of protein import and to change the present protein sourcing from soy bean and fishmeal to sustainable regionally produced proteins and amino acids.

1.2 Aim and Scope

In this report we will take the helicopter perspective of main products or side streams from three main sectors or "Bio-economical Silos" often analysed and treated separately to find potential protein sources: Agriculture, forestry and the marine production systems. In addition, we touch upon the "waste sector" as a potential fourth silo, from which certain side streams could have potentials for feed protein production.

Obviously, agricultural production systems have the largest protein requirement, but they also provide several opportunities to supply more proteins for feedstock themselves. The production of legumes is one contribution, but this report also indicates future opportunities from grass proteins being extracted in a biorefinery process.

Forestry has not traditionally been connected to livestock production but historically side streams from paper production has been used as a substrate to produce fungi used for cattle and poultry feed already in the 1970s (Romantschuk, 1974). Similar single cell protein production is now being re-invented/re-launched with potentials for monogastric feed commercialisation in the future.

The marine ecosystem/production system is undergoing dramatic changes from traditional fishing (for human consumption) and fishing for feed (meal and oils) towards large-scale marine fish farming. Almost half of global seafood stems from aquaculture today. In 2010, Norway produced 1 m tons and EU-27 produced 1.2 m tons – mainly salmon (Meyer, pers. Comm.). Research is now directed towards production of algae and mussels to "catch" nutrients (compensatory production) and to process/refine these marine biomasses for fish and poultry feed (SUBMARINER 2013) with the intention of closing the nutrient cycle.

Finally, the waste sector can provide substrate for insect protein production and we will briefly consult reports and knowledge in this field.

The aim of this report is to establish the first broad overview and preliminary analysis of the potential solutions to the sustainable protein demand challenge. We bring together and analyse existing data to give the overview and discuss potentials, consequences and especially research and study needs, as this field is still emerging.

Several chapters in this report describe specific (ongoing) projects at specific locations. Due to geographic differences, and the fact that these are local projects, the presented results may not be applicable to/or representative for the entire Nordic and Baltic Sea Region. A chapter has been dedicated to a "farmer's perspective". This is primarily seen from a Latvian point of view and also includes a historical interpretation. Finally, a chapter describing Nordic added value related to the sustainable protein production is presented. It outlines the advantages of collaboration across borders and regions from the Nordic viewpoint on e.g. joint learning, sharing of good practices, and the dissemination of the results.

This exercise has revealed serious drawbacks and lack of data for a comprehensive analysis. We are fully aware that answers cannot be given by a single delimited study, but we hope that this report can inspire for more R&D projects in the Nordic Region, the Baltic Sea region and in the EU.

1.3 References

De Boer, H.C., Van Krimpen, M.M., Blonk, H., Tyszler, M. (2014). *Replacement of soybean meal in compound feed by European protein sources*. Effects on carbon footprint. Livestock Research Report 819.

Euractiv, (2011). *MEPs want to end 'protein deficit' for EU livestock*. Retrived from http://www.euractiv.com/cap/eu-parliament-questions-eu-us-blair-house-agreement-news-502925

HELCOM, (2010). *Ecosystem Health of the Baltic Sea (2003–2007)*. HELCOM Initial Holistic Assessment. Balt. Sea Environ. Proc. No. 122.

Meyer, S. (2014). Presentation at Greener Agriculture for Bluer Baltic Sea Conference. *Gessellschaft für Marine Aquacultur* MbH. Schleswig-Holstein.

Schultz-Zehden A. & Matczak M. (eds.), (2012): SUBMARINER Compendium. *An Assessment of Innovative and Sustainable Uses of Baltic Marine Resources.* Gdańsk.

SUBMARINER (2013). *Roadmap towards blue-green economy of the Baltic Sea Region*. Retrieved from www.submariner-project.eu

Romantschuk, H. (1974). *Feeding cattle at the pulp mill in Pasca (ed.) 1974 Unasylva – No. 106 – A time to invest in forestry*. Retrieved from http://www.fao.org/docrep/f1360e/f1360e00.htm#Contents

Winter, T. & Klarlund H. (2014). *A Bioeconomy for the Baltic Sea Region. Impact, engaging the private sector and financing cooperation.* Workshop Paper, Berlin, 18–19 September 2014. Nordic Council Of Ministers.

2. Feed Protein Needs and Nutritive Value of Alternative Feed Ingredients

By *Jan Erik Lindberg*, Swedish University of Agricultural Sciences, Sweden

2.1 Summary

Animal food production in the Nordic countries and in EU as a whole is largely based on imported feed proteins, mainly soybeans. This is not sustainable and calls for alternative feed protein sources that can be produced nationally or regionally. There are several possible alternative feed ingredients that may have the potential to partially or fully replace soybean and fishmeal protein in the diet of livestock and cultured aquatic organisms. The most promising candidates have been identified amongst insects, fungi, bacteria and micro-algae. In addition, there are cultivated plants, which have potential to replace soybean and fish protein in the diet of livestock. The most promising candidates can be found amongst grasses, legumes and grain- and oil seed co-products. However, there is still a lack of data on nutritional properties and animal response on many of the potential candidates. In order to make it possible to perform credible feed formulations and to model possible future use in diets for livestock and fish, data on both the chemical composition and the nutrient availability will be needed. Moreover, in addition to nutrients, alternative feed ingredients may also provide pro-health effects through prebiotic properties, and may contribute to reduce the use of antibiotics in the livestock and aquaculture industry.

2.2 Introduction

On a worldwide basis soybean meal and fishmeal are the main protein sources in the diet for livestock (FAO, 2004). With an increasing animal food production, the supply of protein for livestock from traditional feedstuffs and by-products may not be sufficient to cover the needs in the global livestock industry (FAO, 2004; Leeson, 2012). This calls for increased efforts to identify alternative protein sources that can replace soybean and fishmeal protein in the diet for livestock. However, it has to be understood that this development has to be accomplished within sustainable and environmentally safe food production systems to make sure that the planetary boundaries that have been identified should not be transgressed and, thereby, preventing unacceptable global environmental and climate changes (Rockström *et al.*, 2009).

A major part of the dietary protein used in diets for livestock and aquatic animals in Europe is imported. Soybeans comprise the bulk of the protein import amounting to about 30 million tons annually, which is around 20% of the world production. The use of imported protein for livestock in the Baltic Sea Region (BSR) may be a significant contributing factor for the impact of livestock production on both the environment and the climate. Huge amounts of nutrients (such as nitrogen & phosphorus) are transferred to the food chains through this import and this will contribute to nutrient overload and greenhouse gas emission. The use of locally produced alternative protein-rich feedstuffs could be a means of closing the nutrient circulation in the BSR and, thereby, reduce the negative impact of livestock and aquaculture production. Another possibility is to use microorganisms to produce unique single-cell protein products (Roth, 1980; Stringer, 1982).

There is a range of possible alternative feed ingredients that has been identified and that may have the potential to partially or fully replace soybean and fishmeal protein in the diet of livestock and cultured aquatic organisms. In addition to potential cultivated crops and crop residues, the most promising candidates have been identified amongst insects (Makkar *et al.*, 2014), fungi (Salo, 1979; Langeland, 2014), bacteria (Skrede *et al.*, 1998) and micro-algae (Becker, 2007; Atkinson, 2013).

2.3 Dietary Protein Requirements

In general, the dietary crude protein (CP) requirements for fish and crustaceans is high compared to livestock with a range from 30 to 55% CP of dry matter (DM) for fish and from 30 to 60% CP of DM for shrimp and other crustaceans (Halver & Hardy, 2002; NRC, 2011).

Corresponding figures for pigs are from 12 to 20% CP of DM for reproductive sows, from 20 to 25% CP of DM for piglets and from 13 to 20%

CP of DM for growing pigs (NRC, 2012), and for poultry from 14 to 21% CP of DM for layers and from 20 to 26% CP of DM for broilers (NRC, 1994).

The dietary protein requirements for cattle are from 10 to 19% CP of DM for growing animals and from 13 to 23% CP of DM for dairy cows (NRC, 2001).

However, it should be noted that the level of CP required in the diet will depend on the digestibility and the amino acid (AA) profile. Thus, feed containing ingredients with high CP digestibility and a balanced AA profile can be formulated to contain lower levels of CP than feed with ingredients of low CP digestibility and an unbalanced AA profile. As a consequence, more nitrogen will be excreted with the manure from animals fed diets with low CP digestibility and unbalanced AA profile (Portejoie *et al.*, 2004; Madrid *et al.*, 2013).

2.4 Dietary Amino Acid Requirements

It has to be emphasised that it is not the protein *per se* that should be supplied with the diet, but rather the AA that are needed to build proteins in the body. For the mono-gastric and the aquatic animals, the diet has to provide the required essential AA (EAA) in sufficient quantities and in the right proportions (Halver & Hardy, 2002; NRC, 2011). In contrast, the ruminants are less dependent on the AA profile of the diet, as they are provided with microbial protein (and AA) through the symbiosis with the rumen microbiota (NRC, 2001).

The AA requirements of animals are influenced by factors such as genotype, sex, environment and health status. However, most changes in total AA requirements do not lead to changes in the relative proportions of individual AA (Boisen *et al.*, 2000; van Milgen & Dourmad, 2013). Thus, the AA requirements of EAA can be expressed as an ideal protein usually where the requirement of each individual EAA is expressed relative to the requirement for lysine (i.e. lysine = 100%).

The EAA requirements differ considerably between species, both for lysine and for other EAA, but also within species depending on the physiological performance (Table 1). Thus, the need for supply of AA from feed ingredients will vary.

Table 1: Amino acid requirements of pigs, poultry, fish and shrimp

	Pigs*			Poultry**			Fish & shrimp***	
	Growing pigs, 20–140 kg	Gestating sows	Lactating sows	Broiler chickens, 0–3 weeks	Broiler chickens, 3–6 weeks	Layers	Teleost fish	Penaeid shrimp
Lysine, g/16 g N	7.6–7.1	5.8–5.9	7.4	4.8	5.0	4.6	4.0–6.0	5.2–5.8
EAA, % of Lysine								
Arginine	46	53	56	114	110	102	82	95
Histidine	34	32	40	32	32	24	35	38
Isoleucine	52	55	56	73	73	94	54	48
Leucine	101	95	113	109	109	120	70	81
Methionine	29	28	26	45	38	44	38	48
Met + Cystine	56	69	53	82	72	85	54	65
Phenylalanine	60	57	54	65	65	69	55	55
Phe + Tyrosine	94	98	112	122	122	121	90	100
Threonine	61	76	63	73	74	69	56	67
Tryptophan	17	20	19	18	18	23	14	10
Valine	65	74	85	82	82	102	61	65

Note: * NRC (2012).
** NRC (1994).
*** NRC (2011).

2.5 Nutritive Value of Potential Alternative Feed Ingredients

2.5.1 Insects

There is a long tradition in many parts of Asia, Latin America and Africa to eat insects as part of the human diet (FAO, 2013). It has been estimated that at least 2 billion people eat insects as part of their traditional diet and that more than 1,900 species have been used as food (FAO, 2013). More recently, rearing of insects as a means to enhance food and feed security on a larger scale has come into focus (Makkar *et al.*, 2014). Most insects grow and reproduce easily, have high feed conversion efficiency and can be reared on waste biomass. In the five major groups of insects reviewed by Makkar *et al.,* (2014), the content of CP is high (Table 2). Moreover, the insects were also high in lipids while the carbohydrate content was low and variable. The ash content can reach very high levels although it varied between insects (Makkar *et al.*, 2014).

Table 2: Chemical (g/kg DM) composition, energy content and amino acid composition of insects*

	Black soldier fly larvae	Housefly maggot meal	Housefly pupae meal	Meal worm	Grass-hopper meal	House cricket	Field cricket	Silkworm pupae meal
Crude protein	421	504	708	528	573	633	581	607
Ether extract	260	189	155	361	85	173	103	257
Crude fibre	70	57	157	-	85	-	-	39
Ash	206	101	77	31	66	56	30	58
Gross energy	22.1	22.9	24.3	26.8	21.8	-	-	-
Lysine, g/16 g N	6.6	6.1	5.5	5.4	4.7	5.4	4.8	7.0
EAA, % of Lysine								
Arginine	85	75	89	89	119	113	77	80
Histidine	45	39	36	63	64	43	40	37
Isoleucine	77	52	62	85	85	81	65	73
Leucine	120	88	94	159	123	181	115	107
Methionine	32	36	36	28	49	26	40	50
Met + Cystine	33	47	44	43	72	41	60	64
Phenylalanine	79	75	76	74	72	55	60	74
Phe + Tyrosine	183	152	165	211	142	152	142	159
Threonine	56	57	58	74	75	67	58	73
Tryptophan	8	25	-	11	17	11	-	13
Valine	124	66	76	111	85	94	92	79

Note: * Adapted from Makkar *et al*. (2014).

The CP content of insects is varying but is in the same order or higher as in soybean meal, while the CP content of insects is lower than in fishmeal. The content of lysine in insects may be limiting for pigs (i.e. growing pigs and lactating sows), while it appears to be sufficient for poultry, fish and shrimp (Table 1 & 2). In addition, the content of arginine and sulphur-containing AA (methionine and cystine) may be limiting for poultry and tryptophan appears to be limiting for pigs and poultry. The other EAA are present in amounts meeting or exceeding the requirements.

The high fat content may have an impact on product quality and shelf-life, and could interfere with rumen fermentation. Thus, production of fat-extracted insect products could be a means to avoid the possible negative impact of a high fat content and will also result in a product with higher CP content. Results from animal studies show that insects have potential to partially or fully substitute for soybean meal and fishmeal in diets for ruminants, pigs, poultry, fish and shrimps (Makkar *et al.*, 2014). However, the amount of detailed animal data on the impact of feeding individual insects on digestibility, performance and product quality is varying, and in many cases very limited.

2.5.2 Micro-Algae Biomass

Micro-algae are photoautotrophs that lack roots and leaves, and are rich in chlorophyll a. They are classified as single-cell organisms and have been studied as candidates for alternate protein production since the early fifties (Becker, 2007). In general, micro-algae are high in CP (Table 3), but they are also high in lipids and carbohydrates (mainly non-starch polysaccharides). In addition, they contain important vitamins (Atkinson, 2013; Holman & Malau-Aduli, 2013; Lum *et al.*, 2013). The lipid fraction in micro-algae is rich in poly-unsaturated fatty acids (PUFA) such as docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) and arachidonic acid (Atkinson, 2013; Lum *et al.*, 2013). Present knowledge indicates that algal biomass show promising qualities and potential as novel source of protein for animals, aquatic organisms and humans (Becker, 2007; Atkinson, 2013; Holman & Malau-Aduli, 2013; Lum *et al.*, 2013).

The CP content of micro-algae is varying but is in the same order or higher as in soybean meal, and for some in the same order as in fishmeal. The content of lysine in micro-algae may be limiting for pigs (i.e. growing pigs and lactating sows), while it appears to be sufficient for poultry, fish and shrimp (Table 1 & 3). In addition, the content of sulphur-containing AA (methionine and cystine) may be limiting for poultry and tryptophan appears to be limiting for pigs, poultry and fish. The other EAA are present in amounts meeting or exceeding the requirements.

There may be considerable variability between micro-algae due to species and partly due to culture conditions. The quality of the CP in micro-algae may vary due to the presence of non-protein nitrogen such as nucleic acids, nitrogen-containing cell walls and amines (Lum *et al.*, 2013). Nucleic acids make up approximately 10% of the CP fraction. Results from animal studies are inconsistent, (Holman & Malau-Aduli, 2013; Lum *et al.*, 2013) which calls for further research.

Table 3: Chemical and amino acid composition of microalgae and cyanobacteria

	Chlorella vulgaris*	Dunaliella bardawil*	Spirulina platensis*‡	Arthrospira maxima #	Scenedesmus acutus¤	Scenedesmus obliquus¤
Crude protein	510–580	10–57	600–700	600–710		
Ether extract	140–220	7–30	40–160	60–70		
Crude fibre	-	-	30–70	-		
Ash	-	5–7	30–110	-		
Gross energy	-	-	15.0	-		
Lysine, g/16 g N	6.4	7.0	4.8	4.6	4.6	5.9
EAA, % of Lysine						
Arginine	108	104	152	141		
Histidine	31	26	46	39		
Isoleucine	50	60	140	130	67	69
Leucine	148	157	204	174	152	141
Methionine	20	33	52	30		
Met + Cystine	-	50	71	39	69	49
Phenylalanine	86	83	110	106		
Phe + Tyrosine	130	136	221	191	28	169
Threonine	83	77	129	100	107	140
Tryptophan	-	10	6	30		
Valine	109	83	148	141	102	97

Source: * Lum *et al*. (2013).
Becker (2007).
‡ Holman & Malau-Aduli (2013).
¤ Moo-Young & Gregory (2006)

2.5.3 Microbial Biomass

A fungus is any member of a large group of eukaryotic organisms that includes microorganisms such as yeasts and molds, as well as the more familiar mushrooms. These organisms are classified as the Kingdom Fungi. Fungal cells have cell walls that contain chitin/chitosan, unlike the cell walls of plants, which contain cellulose, and unlike the cell walls of bacteria. Although there are around 1,500 yeast species described, the most commonly used is *Saccharomyces cervisiae* with ability to ferment sugar to carbon dioxide and ethanol. Yeast cells can double their population every 100 minutes under optimal conditions. However, there is great variation in growth rates between strains and between environments.

Rhizopus oryzae and *Paecilomyces varioti* are filamentous micro-fungi found in soil and decaying organic waste, and with a biomass that is rich in protein. They have the ability to produce a range of enzymes making them able to utilise a range of organic waste streams for their growth. *Rhizopus oryzae* has been widely used for food production and for production of different organic substances and extra-cellular enzymes.

Bacteria have a rapid growth rate (doubling time of 20–30 minutes), high protein content and the ability to grow on hydrocarbons and simple nitrogen sources (Kuhad *et al.*, 1997). There is a huge number of bacterial species. However, only a few have been subjected to large-scale production for feed purposes.

The CP content of yeast and fungi is varying but is in the same order as in soybean meal, but lower than in fishmeal. In bacteria, the CP content is higher than in soybean meal and in the same order as in fishmeal. The content of lysine in fungi may be limiting for pigs, poultry, fish and shrimp (Table 1 & 4), depending on the fungal species used. The content of arginine in yeast, bacteria and fungi may be limiting for broilers and layers, and the content of sulphur-containing AA (methionine and cystine) in yeast and fungi may be limiting for poultry. The other EAA in yeast, bacteria and fungi are present in amounts meeting or exceeding the requirements.

Table 4: Chemical (g/kg DM) composition, energy content and amino acid composition of yeast, bacteria and fungi

	Baker's yeast *	Torula ǂ	Bacteria **	Pekilo ǂǂ	Rhizopus ***
Crude protein	466	500	702	500	479
Ether extract	10	20	103	20	94
Crude fibre	-	20		70	
NDF	-	-	-	-	104
Ash	63	70	81	60	121
Gross energy	19.9	-		-	19.7
Lysine, g/16 g N	7.4	7.7	6.1	6.1	3.8
EAA, % of Lysine					
Arginine	65	66	105	100	47
Histidine	30	27	38	33	39
Isoleucine	66	66	79	69	76
Leucine	93	99	128	110	97
Methionine	28	17	49	25	45
Met + Cystine	57	27	59	38	95
Phenylalanine	55	58	70	62	55
Phe + Tyrosine	121	-	133	-	108
Threonine	66	67	79	74	52
Tryptophan	-	18	34	23	-
Valine	81	73	100	80	92

Note: * Saccharomyces cervisiae (Langeland, 2014).
** Methylococcus capsu-latus (>90%), Alcaligenes acidovorans, Bacillus brevi & Bacillus firmus (Skrede *et al*., 1998).
*** Rhizopus oryzae (Langeland, 2014).
ǂ Candida utilis (Salo, 1979).
ǂǂ Paecilomyces varioti (Salo, 1979).

There may be considerable variability between yeast, bacteria and fungi due to species and partly due to culture conditions. The quality of the CP in yeast, bacteria and fungi may vary due to the presence of non-protein nitrogen such as nucleic acids (Kuhad *et al.*, 1997). Nucleic acids can make up 10–20% of the CP fraction (Salo, 1979).

2.5.4 Plant Biomass

There is a range of plants cultivated in the Nordic countries and in the Baltic Sea area, and others that could be introduced for cultivation, which have potential to replace soybean and fish protein in the diet of livestock. The most promising candidates can be found amongst grasses, legumes oilseeds and grain- and oil seed co-products (Jezierny *et al.*, 2010; Kragbaek Damborg Jensen, 2014; Wiryawan & Dingle, 1999; Woyengo *et al.*, 2014; Zanetti *et al.*, 2013). There is a lot of support in the literature that grain legumes (such as faba beans, peas and lupins) and oilseed co-products (such as rapeseed co-products) can partially or completely replace soybean and animal protein in the diet of pigs (Jezierny *et al.*, 2010; Woyenga *et al.*, 2014). However, the plant biomass will contain fibre, and it may contain anti-nutritional factors (ANF) that can have negative impact on nutrient utilisation, performance and health (Jezierny *et al.*, 2010; Woyenga *et al.*, 2014).

The CP content of plant fractions (pulp, juice and green protein) from forages is varying but is in most cases lower than in soybean meal and fishmeal. The highest CP content is obtained in the plant juice and green protein fraction (Table 5). The content of lysine in plant fractions (pulp, juice and green protein) should cover the needs for poultry, fish and shrimp, but may be limiting for growing pigs and lactating sows (Table 1 & 5), depending on the fraction used. The content of sulphur-containing AA (methionine and cystine) in plant fractions (pulp, juice and green protein) will be limiting for pigs, poultry, fish and shrimp. The other EAA in plant fractions (pulp, juice and green protein) are present in amounts meeting or exceeding the requirements.

Table 5: Crude protein content (% in DM) and amino acid composition of forage pulp, juice and green protein (GP)*

	Red clover			Lucerne			White clover			Ryegrass		
	Pulp	Juice	GP	Pulp	Juice	GP	Pulp	Juice	GP	Pulp	Juice	GP
Crude protein	168	250	299	209	292	366	310	326	443	193	194	285
Lysine, g/16 g N	6.9	5.5	6.1	7.2	6.4	6.4	6.8	6.2	6.1	6.4	6.1	5.9
EAA, % of Lysine												
Arginine	78	96	93	76	80	92	88	92	102	98	90	107
Histidine	39	40	39	37	34	39	41	37	41	33	31	37
Isoleucine	74	91	87	69	72	78	78	81	90	80	77	86
Leucine	120	138	136	117	119	134	132	137	152	144	134	156
Methionine	23	27	28	24	23	28	26	26	31	34	29	36
Met + Cystine	38	45	43	40	45	44	40	43	43	50	47	51
Phenylalanine	80	91	93	79	81	94	87	90	103	97	88	107
Phe + Tyrosine	143	176	170	139	153	166	140	148	162	150	144	164
Threonine	75	91	82	68	77	77	78	84	85	80	90	88
Tryptophan	38	51	46	35	42	42	31	34	34	81	33	34
Valine	96	109	108	89	94	100	97	100	110	103	110	113

Note: * Adapted from Kragbaek Damborg Jensen (2014).

The CP content of grain legumes is varying but is lower than in soybean meal and fishmeal. The highest CP content is found in faba beans and lupines (Table 6). The content of lysine in faba beans and peas should cover the needs for poultry, fish and shrimp, but may be limiting for growing pigs and lactating sows (Table 1 & 6). The lysine content in lupines is below requirements for poultry but may cover the needs for fish. The content of sulphur-containing AA (methionine and cystine) in faba beans, peas and lupines is low and will be limiting for pigs, poultry, fish and shrimp. Moreover, the content of isoleucine, threonine, tryptophan and valine in faba beans and peas will be limiting for pigs and poultry. The other EAA in grain legumes are present in amounts meeting or exceeding the requirements.

Table 6: Chemical (g/kg DM) composition, energy content and amino acid composition of legume grains, rapeseed meal and linseed meal*

	Vicia faba	Pisum sativum	Lupinus	Rape seed meal	Linseed meal	Soybean meal
Crude protein	301	246	324–381	380	342	516
Ether extract	13	12	59–95	26	90	22
Crude fibre	87	60	129–165	140	113	68
Ash	42	35	38–39	79	65	73
Gross energy	18.7	18.3	20.2–21.2	19.2	20.5	19.7
Lysine, g/16 g N	6.1	7.0	4.5–4.6	5.3	3.8	6.1
EAA, % of Lysine						
Arginine	143	121	220	113	237	121
Histidine	42	35	45	49	71	44
Isoleucine	64	58	94	75	110	75
Leucine	116	100	147	126	150	121
Methionine	12	13	16	38	45	23
Met + Cystine	31	33	49	85	97	47
Phenylalanine	68	68	79	74	126	82
Phe + Tyrosine	116	107	175	128	187	138
Threonine	57	53	75	81	100	64
Tryptophan	14	13	14	23	39	21
Valine	72	66	88	96	126	79

Note: * Compiled from Jezierny *et al.* (2010) and Sauvant *et al.* (2004).

The CP content of rapeseed meal and linseed meal is lower than in soybean meal and fishmeal (Table 6). The content of lysine in rapeseed meal should cover the needs for poultry, fish and shrimp, but will be limiting for growing pigs and lactating sows (Table 1 & 6). The lysine content in linseed meal is below requirements for pigs, poultry, fish and shrimp. The content of sulphur-containing AA (methionine and cystine) in rapeseed meal and linseed meal should cover the needs for pigs, fish and shrimp but may be limiting for poultry. The other EAA in rapeseed meal and linseed meal are present in amounts meeting or exceeding the requirements.

2.6 Assessment of Feeding Value

In order to fully evaluate the potential of alternative feedstuffs of varying origin, a thorough chemical analysis of major nutrients (protein, fat, carbohydrates & minerals) should be performed. At present there is a lack of data on the gross chemical composition, and even more so on more detailed analytical data (e.g. AA, fatty acids, minerals), of insects and microbes with possible potential to be used as animal feed protein sources (Atkinson, 2013; Makkar *et al.*, 2014). In addition to chemical analysis, animal experiments should be performed in order to evaluate the availability and utilisation of nutrients and energy. At present, there are limited published data available on digestibility and performance in important animal species. The bulk of experimental in vivo data found are on fish and poultry with much less on pigs and even more limited data on ruminants (Makkar *et al.*, 2014). This is largely due to difficulties to get enough quantities of novel feed ingredients to be able to perform animal experiments. Thus, in order to make it possible to perform credible feed formulations and to model possible future use in diets for livestock and fish, data on both the chemical composition and the nutrient availability will be needed.

2.7 Possible Constraints Linked to Novel Protein Ingredients

There are several components in insects and microbes that may limit their general use or may limit the inclusion level in the diet for food producing livestock and aquatic organisms. High ash content (e.g. insects, micro-algae) may interfere with the digestion and an unbalanced mineral composition with the mineral supply.

Dietary fibre (DF) has an important role in diets for mono-gastric animals and a minimum level of DF has to be included to maintain normal physiological function in the digestive tract (Wenk, 2001; Svihus, 2011). However, although there are large differences between DF sources, in general the digestibility of DF is low. Thus, inclusion of DF in diets for mono-gastric animals is often associated with decreased nutrient utilisation and low net energy values (Noblet & Le Goff, 2001). Chitin (e.g. insects, fungi) is a poly-glucosamine [ß-(1→4)-2-acetamido-D-glucose and ß-(1→4)-2-amino-D-glucose] that is classified as DF and is poorly digested in mono-gastric animals. In contrast, chitosan is a de-acetylated form of chitin, which is soluble in acidic solutions and is partially digested in mono-gastric animals (Swiatkiewicz *et al.*, 2014). Moreover, fish (Fines & Holt, 2010) and shrimp (Clark *et al.,* 1993) appear to have the capacity to digest chitin.

Grain legumes (such as faba beans, peas, lupines, soy beans) contain a number of secondary bioactive metabolites that have been described as positive, negative or both (Jezierny *et al.*, 2010). However, most secondary plant metabolites, such as condensed tannins, protease inhibitors, alkaloids, lectins, pyrimidine glycosides and saponins are classified as anti-nutritional factors (ANF) due to their negative impact on growth performance, fertility and health status of livestock. In addition to condensed tannins, rapeseed and its co-products contain glucosinolates, which is an ANF that may affect palatability and feed intake and can have negative impact of animal performance (Woyengo *et al.*, 2014). Heat-labile ANF (such as protease inhibitors and lectins) are sensitive to temperature and can be de-activated by feed processing, while the heat-stabile ANF (such as condensed tannins, alkaloids, pyrimidine glycosides and saponins) will be un-affected by feed processing.

High content of nucleic acids (DNA, RNA, nucleotides) in single-cell protein (SCP) have limited their use in human nutrition because of limited metabolic capacity which results in elevated levels of uric acid in blood (hyperuricemia) (Giesecke & Tiemeyer, 1982). Whether this also applies in general to mono-gastric animals will depend on the microbial ecology of the gut, the activity of intestinal nucleolytic enzymes and purine and pyrimidine absorption and metabolism. Replacing traditional protein sources with Pekilo protein in diets for pigs (Alaviuhkola, 1979; Hanssen, 1979a) and poultry (Hanssen, 1979b; Kiiskinen, 1979) showed very good performance results without any reported negative impact on animal wellbeing. Pekilo is a SCP product from the filamentous micro-fungi *Paecilomyces varioti* grown on sulphite spent liquor and with a nucleic acid content of around 10% of dry matter (DM) or 20% of CP (Salo, 1979). Moreover, growing pigs fed bacterial protein containing around 10% of nucleic acids in DM (Helwig *et al.*, 2007) did not show any uricogenic effect.

There may be a risk for uptake and accumulation of heavy metals, pesticides, toxins and pathogens in insects, microorganisms and micro-algae (Kuhad *et al*., 1997; Lum *et al.*, 2013; Makkar *et al.*, 2014) if they are grown on polluted and contaminated substrates.

2.8 Possible Health Promoting Effects of Alternative Protein Sources

Beta-glucans, chitin and galacto-oligosaccharides are used as pro-health feed supplements for livestock and aquatic animals, and may contribute to a reduced therapeutic use of antibiotics. They can be classified as prebiotic compounds as they are non-digestible food ingredients that are fermented by the microbiota colonising the gastro-intestinal (GI) system and selectively stimulates the growth and/or the activity of one or a limited number of bacteria within the GI system.

Beta-glucans are usually isolated from the cell wall of bacteria, yeast, fungi and algae (Soltanian *et al.*, 2009; Lam & Cheung, 2013). Their biological activity is influenced by the degree of branching, size and the molecular structure. Beta-glucans have beneficial effects on gut health and can have immunostimulatory effects.

Chitosan, the de-acetylated form of chitin, is used as a feed additive to poultry and pigs and show some beneficial immunomodulatory, anti-oxidative, antimicrobial and hypo-cholesterolemic properties (Swiatkiewicz *et al.*, 2015). In addition, these properties of chitosan were reflected in improved performance (body weight gain and/or feed conversion ratio) and nutrient digestibility in broiler chickens and weaned pigs.

Galacto-oligosaccharides or α-galactosides are soluble low-molecular weight oligosaccharides of the raffinose family, such as raffinose, stachyose and verbascose that can be found in grain legumes. The content of galacto-oligosaccharides vary among grain legumes with relatively high levels in lupins as compared with faba beans, peas and soy beans (Jezierny *et al.*, 2010).

2.9 Organic and Conventional Animal Production

It is not allowed to use synthetic AA in organic animal production, which leads to an over-supply of dietary CP to make sure that the minimum requirements for EAA are fulfilled (Høøk Presto, 2008). This results in higher excretion of nitrogen via the manure, which increases the risk of nitrogen losses. The reason for the over-supply is that most feedstuffs available for organic (and conventional) feed formulation are lacking important and limiting EAA, such as lysine and methionine. However, in contrast to organic animal production the conventional animal production allows the use of synthetic AA, which makes it possible to balance the EAA profile of the diet without having to increase the dietary CP content.

2.10 Environmental Impact of Dietary Protein

A large part of the nitrogen contained in the feed for livestock is lost to the surrounding environment, among others as ammonia to the atmosphere. It was estimated that one-third of the nitrogen fed to slaughter pigs is retained in the body, one-third is lost via the nitrogen emission and one-third is excreted with the manure (Portejoie *et al.*, 2004). The most important measure to reduce nitrogen losses from manure is to reduce the amount of CP in the diet (Portejoie *et al.*, 2004; Velthof *et al.*, 2005). However, due to fluctuations in the price of raw materials and variations in crude protein content, it is either too expensive or technically impossible to formulate a nutrient balanced feed with a desired minimum content of CP.

Increasing the fiber content in the diet increases the gut microbial activity, which results in production of organic acids in the gut and a lower pH in faeces. The increased microbial activity in the gut also results in more nitrogen being bound in microbial proteins and excreted with the faeces. Overall, this results in a reduction in the emission of nitrogen (Canh *et al.*, 1998; Gerdemann *et al.*, 2000; Sørensen & Fernandez, 2003; Clark *et al.*, 2005). Moreover, the type of fiber in the diet may affect the emission (Canh *et al.,* 1998) and have an impact on the utilisation of nitrogen in manure by plants (Fernandez & Sørensen, 2003).

2.11 References

Alaviuhkola, (1979). *Experiences on feeding pigs with Pekilo*. In: Research report of Pekilo-symposium, Tampere 12-15/9, 1978 (Ed. T. Kiiskinen). Agricultural Research Centre, Institute of Animal Husbandry, Report No. 12, pp 33–45.

Atkinson, N., (2013). The potential of microalgae meals in compound feeds for aquaculture. *International Aqua Feed 16* (5), 14–17.

Austic, R. E., Mustafa, A., Jung, B., Gatrell, S. & Lei, X. G., (2013). Potential and limitation of a new defatted diatom microalgal biomass in replacing soybean meal and corn in diets for broiler chickens. *Journal of Agricultural and Food Chemistry 61*, 7341–7348. http://dx.doi.org/10.1021/jf401957z

Becker, E. W., (2007). Micro-algae as a source of protein. *Biotechnology Advances 25*, 207–210. http://dx.doi.org/10.1016/j.biotechadv.2006.11.002

Boisen, S., Hvelplund, T. & Weisbjerg, M. R., (2000). Ideal amino acid profiles as a basis for feed protein evaluation. *Livestock production Science 64*, 239-251. 698–706. http://dx.doi.org/10.1016/S0301-6226(99)00146-3

Canh, T.T., Sutton, A.L., Aarnink, A. J. A., Verstegen, M. W. A., Schrama, J. W. & Bakker, G. C. M. (1998). Dietary carbohydrates alter the fecal composition and pH and ammonia emission from slurry of growing pigs. *Journal of Animal Science 76*, 1887–1895.

Clark, D. J., Lawrence, A. L. & Swakon, D. H. D., (1993). Apparent chitin digestibility in penaeid shrimp*. Aquaculture 109*, 51–57. http://dx.doi.org/10.1016/0044-8486(93)90485-H

Clark, G.C., Moehn, S, Edeogu, I., Price, J. & Leonard, J., (2005). Manipulation of dietary protein and non-starch polysaccharide to control swine manure emissions. *Journal of Environmental Quality 34*, 1461–1466. http://dx.doi.org/10.2134/jeq2004.0434

FAO, (2013). *Edible insects: future prospects for food and feed security*. Forestry paper 171. FAO, Rome, Italy.

FAO, (2004). *Protein sources for the animal feed industry.* Proceedings from the Expert consultation and workshop, Bangkok 29 April to 3 May 2002. FAO, Rome, Italy.

Fines, B. C. & Holt, G. J., (2010). Chitinase and apparent digestibility of chitin in the digestive tract of juvenile cobia, Rachycentron canadum. *Aquaculture 303*, 34–39. http://dx.doi.org/10.1016/j.aquaculture.2010.03.010

Gerdemann, M.M., Machmuller, A., Frossard, E. & Kreutzer, M., (2000). Effect of different feeding strategies on nitrogen fertilization value of slurry for Lolium multiforum*. Journal of Plant Nutrition and Soil Science 162* (4), 401–408. http://dx.doi.org/10.1002/(SICI)1522-2624(199908)162:4<401::AID-JPLN401>3.0.CO;2-V

Giesecke, D. & Tiemeyer, W., (1982). Availability and metabolism of purines of single-cell proteins in monogastric animals. *Proceedings of the Nutrition Society 41*, 319–327. http://dx.doi.org/10.1079/PNS19820047

Halver, J. D. & Hardy, R. W., (2002). *Fish nutrition*. 3rd edition. Academic Press, USA.

Hanssen, (1979a). *Nutritional experiences on feeding pigs with the Pekilo*. In: Research report of Pekilo-symposium, Tampere 12-15/9, 1978 (Ed. T. Kiiskinen). Agricultural Research Centre, Institute of Animal Husbandry, Report No. 12, pp 54–64.

Hanssen, (1979b). *Experiences with the Pekilo protein as a protein source in poultry feeding in Norway.* In: Research report of Pekilo-symposium, Tampere 12-15/9, 1978 (Ed. T. Kiiskinen). Agricultural Research Centre, Institute of Animal Husbandry, Report No. 12, pp 65–70.

Hellwig, A. L. F., Tauson, A. H. & Skrede, A., (2007). Excretion of purine base derivatives after intake of bacterial protein meal in pigs. *Livestock Science 109*, 70–72. http://dx.doi.org/10.1016/j.livsci.2007.01.070

Holman, W. B. & Malau-Aduli, A. E. O., (2013). Spirulina as a livestock supplement and animal feed. *Animal Physiology and Animal Nutrition 97*, 615–623. http://dx.doi.org/10.1111/j.1439-0396.2012.01328.x

Høøk Presto, M., (2008). *Organic pig meat production-Nutrient supply, behaviour and health.* Swedish University of Agricultural Sciences, Acta Universitatis Agriculturae Sueciae, Faculty of Veterinary Medicine and Animal Science, Doctoral thesis no. 2008:97.

Jezierny, D., Mosenthin, R. & Bauer, E., (2010). The use of grain legumes as a protein source in pig nutrition: A review. *Animal Feed Science and Technology 157*, 111–128. http://dx.doi.org/10.1016/j.anifeedsci.2010.03.001

Kiiskinen, (1979). *Pekilo in the feeding of poultry.* In: Research report of Pekilo-symposium, Tampere 12-15/9, 1978 (Ed. T. Kiiskinen). Agricultural Research Centre, Institute of Animal Husbandry, Report No. 12, pp 133–143.

Kragbaek Damborg Jensen, V., (2014). *Protein yields and amino acid characterization of juice and pulp from white clover, red clover, lucerne and ryegrass*. Aarhus University, Aarhus School of Engineering, Master Thesis.

Kuhad, R. C., Singh, A., Tripathi, K. K., Saxena, R. K. & Eriksson, K. E. L., (1997). Microorganisms as an alternative source of protein. *Nutrition Reviews 55*(3), 65–75. http://dx.doi.org/10.1111/j.1753-4887.1997.tb01599.x

Lam, K. L. & Cheung, C. K., (2013). Non-digestible long chain beta-glucans as novel prebiotics. *Bioactive Carbohydrates and Dietary Fibre 2*, 45–64. http://dx.doi.org/10.1016/j.bcdf.2013.09.001

Langeland, M., (2014). *Nutrition of Arctic charr (Salvelinus alpinus) and Eurasian perch (Perca fluviatilis) and evaluation of alternative protein sources*. Swedish University of Agricultural Sciences, Acta Universitatis agriculturae Sueciae, Faculty of Veterinary Medicine and Animal Science, Doctoral thesis no. 2014:39.

Leeson, S. (2012). Future considerations in poultry nutrition. *Poultry Sci. 91*:1281–1285. http://dx.doi.org/10.3382/ps.2012-02373

Lum, K. K., Kim, J. & Lei, X. G., (2013). Dual potential of microalgae as a sustainable biofuel feedstock and animal feed. *Journal of Animal Science and Biotechnology 4*, 53. http://dx.doi.org/10.1186/2049-1891-4-53

Madrid, J., Martinez, S., Lopez, C., Orengo, J., Lopez, M. J. & Hernandez, F., (2013). Effects of low protein diets on growth performance, carcass traits and ammonia emissions of barrows and gilts. *Animal Production Science 53*, 146–153. http://dx.doi.org/10.1071/AN12067

Makkar, H. P. S., Tran, G., Heuzé, V. & Ankers, P., (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science and Technology 197*, 1–33. http://dx.doi.org/10.1016/j.anifeedsci.2014.07.008

Moo-Young, M. & Gregory, K. F., (1986). *Microbial biomass proteins*. Springer Science & Business Media.

Nahm, K. H., (2002). Efficient feed nutrient utilization to reduce pollutants in poultry and swine manure. *Critical Review in Environmental Science and Technology 32* (1), 1–16. http://dx.doi.org/10.1080/10643380290813435

Noblet, J. & Le Goff, G. I., (2001). Effect of dietary fibre on the energy value of feeds for pigs. *Animal Feed Science and Technology 90*, 35–52. http://dx.doi.org/10.1016/S0377-8401(01)00195-X

NRC, (1994). *Nutrient requirements of poultry.* 9th revised edition. Subcommittee on Poultry Nutrition, National Research Council. The National Academic Press, Washington DC, USA.

NRC, (2001). *Nutrient requirements of dairy cattle.* 7th revised edition. Subcommittee on Dairy Cattle Nutrition, National Research Council. The National Academic Press, Washington DC, USA.

NRC, (2011). *Nutrient requirements of fish and shrimp*. Committee on the Nutrient Requirements of Fish and Shrimp, National Research Council of the National Academies. The National Academic Press, Washington DC, USA.

NRC, (2012). *Nutrient requirements of swine*. 11th revised edition. Committee on the Nutrient Requirements of Swine, National Research Council of the National Academies. The National Academic Press, Washington DC, USA.

Portejoie, S., Dourmad, J-Y., Martinez, J. & Lebreton, Y., (2004). Effect of lowering dietary crude protein on nitrogen excretion, manure composition and ammonia emission from fattening pigs. *Livestock Production Science 91*, 45–55. http://dx.doi.org/10.1016/j.livprodsci.2004.06.013

Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin III, E. F. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. J. Schellnhuber, B. Nykvist, C. A. de Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman,

K. Richardson, P. Crutzen and J. A. Foley. (2009). A safe operating space for humanity. *Nature 461*:472–475. http://dx.doi.org/10.1038/461472a

Roth, F. X., (1980). Micro-organisms as a source of protein for animal nutrition. *Animal Research and Development 12*, 7–19.

Salo, M. L., (1979). *Chemical composition and feed value of the pekilo*. In: Research report of Pekilo-symposium, Tampere 12-15/9, 1978 (Ed. T. Kiiskinen). Agricultural Research Centre, Institute of Animal Husbandry, Report No. 12, pp 9–20.

Skrede, A., Berge, G. M., Storebakken, T., Herstad, O., Aarstad, K. G. & Sundstøl, F., (1998). Digestibility of bacterial protein grown on natural gas in mink, pigs, chicken and Antlantic salmon. *Animal Feed Science and Technology 76*, 103–116. http://dx.doi.org/10.1016/S0377-8401(98)00208-9

Soltanian, S., Stuyven, E., Cox, E., Sorgeloos, P., & Bossier, P., (2009). Beta-glucans as immunostimulant in vertebrates and invertebrates. *Critical Reviews in Microbiology 35*(2), 109–138. http://dx.doi.org/10.1080/10408410902753746

Stringer, D. A., (1982). Industrial development and evaluation of new protein sources: micro-organisms. *Proceedings of the Nutrition Society 41*, 289–300. http://dx.doi.org/10.1079/PNS19820044

Svihus, B. (2011). The gizzard: function, influence of diet structure and effects on nutrient availability. *World's Poultry Science Journal 67*, 207–224. http://dx.doi.org/10.1017/S0043933911000249

Swiatkiewicz, S., Swatkiewicz, M., Arczewska-Wlosek, A. & Jozefiak, D., (2014). Chitosan and its oligosaccharide derivatives (chito-oligosaccharides) as feed supplements in poultry and swine nutrition. *Journal of Animal Physiology and Animal Nutrition 99*, 1–12. http://dx.doi.org/10.1111/jpn.12222

Sørensen, P. & Fernandez, J. A., (2003). Dietary effects on the composition of slurry and on the plant utilization of pig slurry manure. *Journal of Agricultural Science 140*, 343–355. http://dx.doi.org/10.1017/S0021859603003113

Van der Peet-Schwering, C. M. C., Aarnink, A. J. A., Rom, H. B. & Dourmad, J. Y., (1999). Ammonia emissions from pig houses in The Netherlands, Denmark and France. *Livestock Production Science 58*, 265–269. http://dx.doi.org/10.1016/S0301-6226(99)00017-2

Van Milgen, J. & Dourmad, J. Y., (2015). Concept and application of ideal protein for pigs. *Journal of Animal Science and Biotechnology 6*:15. http://dx.doi.org/10.1186/s40104-015-0016-1

Velthof, G. L., Nelemans, J. A., Oenema, O. & Kuikman, J., (2005). Gaseous nitrogen and carbon losses from pig manure derived from different diets. *Journal of Environmental Quality 34*(2), 698–706. http://dx.doi.org/10.2134/jeq2005.0698

Wenk, C. (2001). The role of dietary fibre in the digestive physiology of the pig. *Animal Feed Science and Technology 90*, 21–33. http://dx.doi.org/10.1016/S0377-8401(01)00194-8

Wiryawan, K. G. & Dingle, J. G., (1999). Recent research on improving the quality of grain legumes for chicken growth. *Animal Feed Science and Technology 76*, 185–193. http://dx.doi.org/10.1016/S0377-8401(98)00218-1

Woyengo, T. A., Beltranena, E. & Zijlstra, R. T., (2014). Controlling feed cost by including alternative ingredients into pig diets: A review. *Journal of Animal Science 92*, 1293–1305. http://dx.doi.org/10.2527/jas.2013-7169

Zanetti, F., Monti, A. & Berti, M. T., (2013). Challenges and opportunities for new industrial oilseed crops in EU-27: A review. *Industrial Crops and Products 50*, 580–595. http://dx.doi.org/10.1016/j.indcrop.2013.08.030

3. Mapping of Protein Sources and Use

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3.1 Introduction

A bioeconomy is defined as an economy where the basic building blocks for materials, chemicals, and energy are derived from renewable biological resources. Bioeconomy is currently one of the key thematic areas of Nordic Council of Ministers. A number of Nordic initiatives have been taken in 2014–2015 in order to gain a deeper understanding on the Nordic bioeconomy, its key initiatives, and future potential. There are, however, challenges remaining in mapping the bioeconomy-related resources, initiatives, and output of the Nordic bioeconomy. The mapping of protein sources and use, as well as future development in protein (forestry, aquaculture, grass, etc.), is clearly in line with this understanding of the bioeconomy.

The purpose of this dimension of the sustainable proteins project has been to scope the possibilities for mapping protein supply and use in the Nordic and Baltic region, and to make preparations for a joint framework for a more in-depth mapping/analysis of the Nordic and BSR region protein sources and their potential.

The implementation of a full mapping exercise of protein sources and use in Nordic and BS-regions would be a logical and welcomed step towards gaining deeper quantitative and qualitative understanding of the nature and potential of current and planned sustainable protein initiatives in a Nordic and Baltic context. The scale of such a full-scale exercise would, however, go far beyond the activities of this scoping project.

As of today, there is no appropriate holistic data or knowledge on Nordic and Baltic proteins available; and the case is similar globally. E.g. the FAO states in relation to protein mapping that quantity of animals and human consumption are rather well mapped, but that "data on feed production and consumption are much harder to assemble, and FAO does not have comprehensive information about these important commodities" (FAO 2004). Add the dimension of fish, aquaculture, insects and grass – and the task of mapping protein becomes truly immense.

Case studies might be one way forward for comprehending the situation for sustainable protein production and use, but since proteins are globally traded commodities this only provides pieces of the puzzle. However, for the BSR the process needs to start with mapping of resources: forestry, agriculture, marine production, etc. in Nordic and Baltic regions – statistics, trends, maps, and cases.

In our opinion, mapping of proteins should be carried out in both quantitative and qualitative dimensions; these should include elements of "taking stocks" as well as "looking forward". It should also be understood that mapping of resources and activities is only one part of collecting the pieces of the puzzle; the information needs to be combined with knowledge about conversion ratios and possibilities for substitution in order to learn about the future demand and sources of protein.

The quantitative dimension amounts to hard facts and figures about land and animals in the countries. This could potentially be detailed down to the species of aquaculture, horticulture, animal husbandry and land use. In general, what is mapped when it comes to agricultural animals is the protein use and conversion of pigs, bovine animals, poultry, horses, sheep and goats. Detailed information about land use, harvested crops and vegetables, pastures and feed production is also available – and can easily overflow any mapping exercise; delimitation of what is the important aspects to map in a country or region is important. For fisheries and aquaculture the fishing/landing, growing and processing of most fish is available in databases; but following the market channels and the final destination of proteins is not easy. Hence, taking stocks is a tremendous exercise and one, which should be clearly focused. Forward-looking in the domain of quantitative mapping involves spotting trends in the consumption and production of proteins; something which involves understanding human population development, food habits, new emerging sources of protein, and competition from alternative uses of land and produce (e.g. for energy, infrastructure).

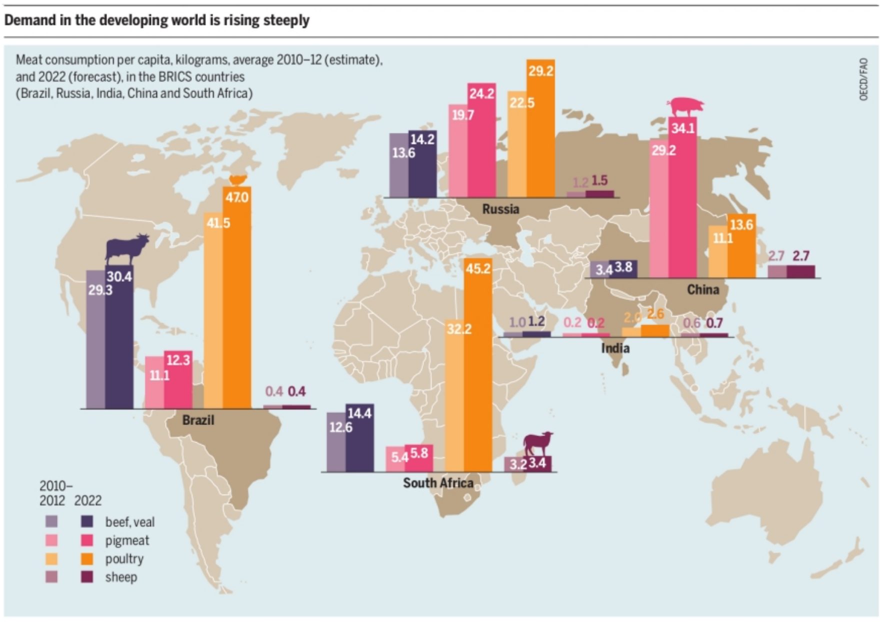
The qualitative dimension should tell the story of protein use, and production from a more dynamic perspective – in a specific place. This place could be of different scale, e.g. a region, country or the BSR. This dimension should focus on bottlenecks, regional stocks and flows, future intrinsic development paths, development projects and hot-spots when it comes to protein. Such a qualitative mapping will also facilitate learning between places, and helps to display what is at the "front" when it comes to protein efficiency, new products developed, and re-use.

3.2 Mapping of Protein Sources and Use: The Global Context

Due to the global increase in the world's population, and the changing dietary habits of populations of developing countries the FAO and other institutions suggest that global meat production and consumption will rise from 233 million tons (2000) to 300 million tons (2020), and milk from 568 to 700 million tons over the same period. Egg production will also increase by 30%. These predictions show a massive increase in animal protein demand. For instance, China has gone through a transition when it comes to imports of agricultural commodities, from wheat being the most important, to soy now holding the first place.

In developed countries, meat consumption is slowing down, and even at some places decreasing. In developing countries the consumption has continued to increase, and is projected to continue to do so, see Figure 1.

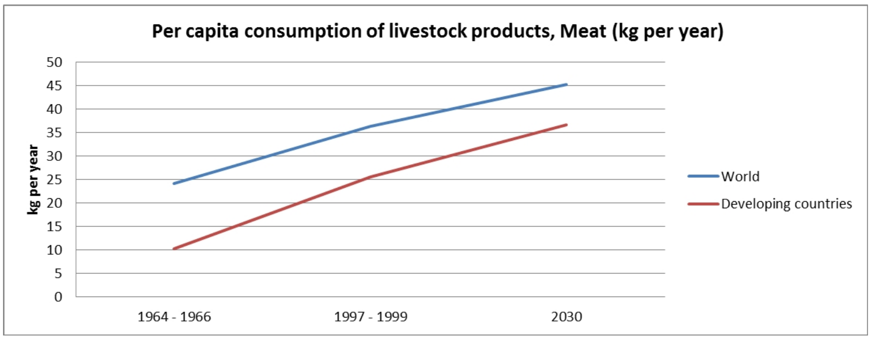
Figure 1: Meat consumption over time, different types of meat, developing countries



Source: FAO/OECD (2013).

This projected increase, summarised in Figure 2 will obviously put pressure on the production of high-value proteins for feed. It will also demand tremendous amounts of water in order to produce feed. Projections indicate that pig-feed is that of most extreme increase.

Figure 2: Projected world growth in meat consumption and demand for animal feed



Source: Adopted from WHO (http://www.who.int/nutrition/topics/3_foodconsumption/en/index4.html).

This growth in animal feed will not only be constituted through an increase in cereals, but also of other feeds, and particularly proteins. According to a FAO publication (Protein sources for the animal feed industry, FAO 2004) "data on feed production and consumption are much harder to assemble, and FAO does not have comprehensive information about these important commodities".

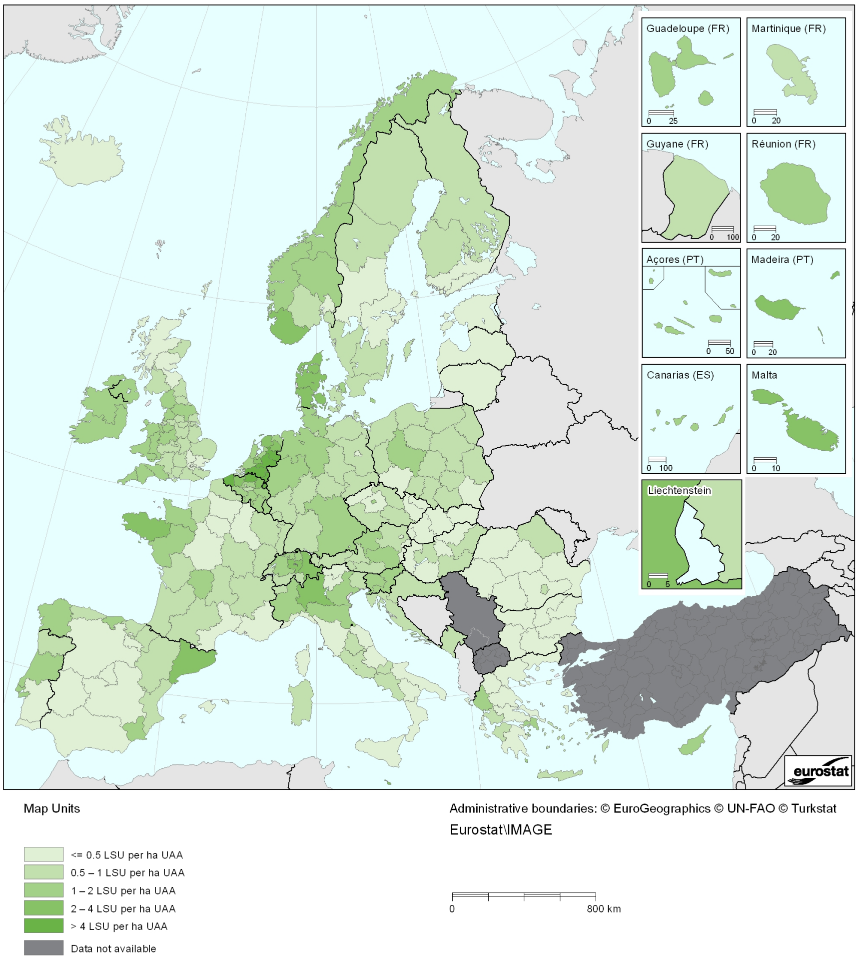
Above all, quality protein will be required to satisfy the increase in milk and meat production, particularly as the latter will come mostly from poultry and pigs. The FAO have made some projections, although conversion ratios are uncertain for the feed for pigs, poultry and other animals, which will be produced more intensively in the future. These indicate that the requirements for protein meals will continue to increase at a steep rate. Historically protein meals have been made up of mainly safflower and soy meals, and it is perceived that these high protein products will be more intensively produces and traded also in the future.

3.3 Mapping of Protein Sources and Use: The European Development and Context

As mentioned above the mapping of protein use and production must be based on both facts about structure in BSR/Europe and the knowledge about production systems and feed/protein use and conversion. Hence, this chapter will only set out to display what is available at the European (and sometimes regional) scale. The material is collected primarily from Eurostat as this is the only available source for harmonised data of this kind. Obviously, a rigorous mapping in any given country can draw on NSI (national statistics) to make the picture even more detailed.

Concerning livestock, animal intensity and development trajectories, there are aggregate data for most countries and types of animals. Regional intensity maps are produced (at NUTS 2 level), which shows the hotspots when it comes to pressure (and also use of protein for feed), see Figure 3.

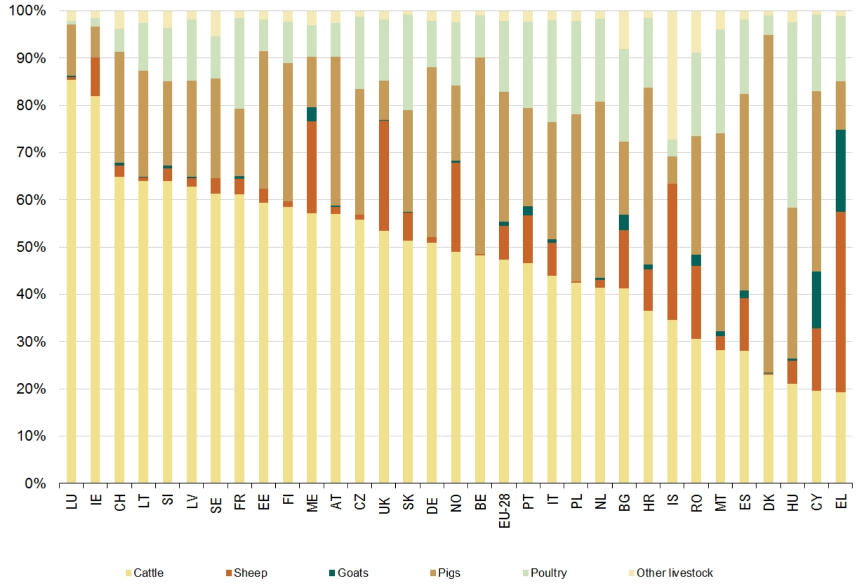
Figure 3: Example of European data; livestock at regional level



Source: Eurostat database.

As evident from the diagram below in Figure 4, the differences in agricultural production is rather large in the BSR, with Poland (and Germany, which is partly included in the BSR) standing out. Obviously, Denmark is important in the pig production, but in total terms (not in the diagram) the difference is not as dramatic compared to Poland and Germany.

Figure 4: Example of European data; Livestock patterns

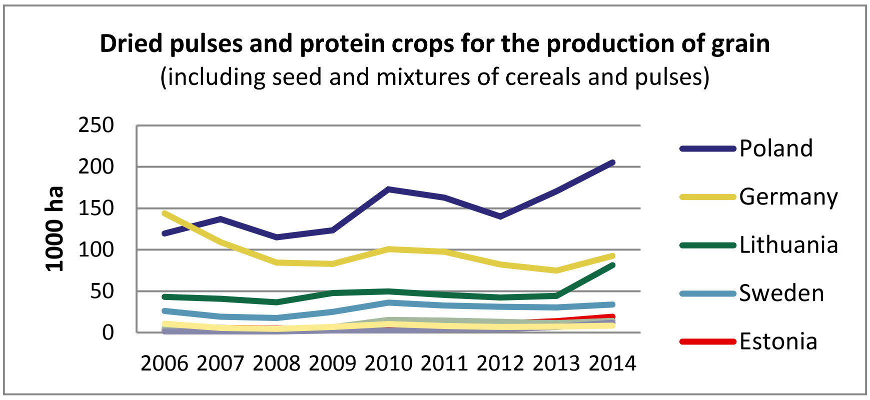


Source: Eurostat database.

Reviewing data about the utilised agricultural area (in %), we see that most land is utilised already in Denmark and in Lithuania and in southwest Sweden, the utilisation is around 40%. In Poland, the fallow land has decreased dramatically since EU-programs started, and now the situation is similar as to other central-European countries, around 40–50%. Overall, in many regions in the BSR, there is still quite a lot of agricultural land that could potentially be used for producing proteins (for feed or animal consumption). However, imported soy-meals and other forms of protein constitute a better, more economical, option at this time. The domestic production of fodder has also remained rather constant for all countries over the last years.

In some countries, like Poland, Germany and Lithuania, the production of protein crops has actually increased in the last few years, see Figure 5. This could be the result of proteins becoming more demanded and more expensive on the world markets. Soybean prices reached a top in mid-2012, and then again in early 2014 (dairy increased in 2013, pulling soy with it), before falling together with the rest of world market food prices. Hence, we might expect to see some increase in domestic production of protein crops for human and animal consumption as world markets respond to increases in meat production globally.

Figure 5: Example of European data; protein crops in BSR countries



Source: Eurostat database.

When it comes to fisheries and aquaculture the material in Eurostat is usually divided into catchment areas; and available data is concerned with aspects such as total catches. Furthermore, there are some data and maps of aquaculture production, and this can also be broken down into species being cultivated.

3.4 Proposal for a "Framework for Future Survey on Protein Potential"

If we want to move further than these statistics and learn more about what is going on when it comes to proteins in the countries and regions, it seems necessary to develop some sort of survey for detecting both new quantitative and qualitative trends in protein use and provision. The idea would be to provide an overview of the situation and current trends. Such a survey could be implemented within the realms of a larger protein mapping project, and could ideally be developed together with experts, and filled out in consecutive rounds including feedback and joint learning.

National and regional experts on protein related sectors should be the main informants; and the sectors to cover should include:

- Agriculture.
- Marine resources and biomass.
- Forest and wood-biomass.
- Other sources.

For instance, the dimensions to cover for each of these could be similar and using the example of agriculture they could be made up of:

- Total arable land for crop production.
- Agricultural fallow land availability.
- Key sources of proteins within national agriculture (and future sources).
- Agricultural protein crop production (to calculate protein production).
- National hot-spot(s) in new protein production or conversion in agricultural crops.
- Current livestock levels, species and levels (to calculate protein use).
- National hot-spot(s) in new protein production or conversion in agricultural animals.
- Major feed protein needs in agriculture.
- Net balance of production and consumption of proteins.

Information on these sources could be collected both from statistical sources and from experts. Specifically aspects such as "key-sources for protein (and future sources)", "National hot-spot(s) in new protein production or conversion in agricultural crops", and other aspects of interesting new developments, should be areas for discussion and qualitative assessments.

3.5 References

EUROSTAT: Maps and graphs generated form the database in June–July 2015. http://ec.europa.eu/eurostat/data/database

FAO (2004). *Protein sources for the animal feed industry*. Expert Consultation and Workshop. Bangkok, 29 April – 3rd May 2002.

FAO/OECD (2013). *Agricultural Outlook 2013–2022*.

Nordregio Working Paper 2014:4 *Bioeconomy in the Nordic regions*. Nordregio.

4. Regional Potentials in Protein Supply from Agriculture

By *Gert Poulsen,*[1] *Svein Øivind Solberg,*[1] and *Knud Tybirk,*[2] University of Copenhagen, Denmark,[1] Agro Business Park, Denmark[2]

4.1 Introduction

In this section, we present an overview of agricultural plants as bio-resources for protein for the animal and fish feed industry, promoting more economically and environmentally sustainable agricultural production systems in the Baltic Sea region. The aim is to map the status and economy of protein crops cultivated in the countries and to give recommendations to political processes to move forward. This section is based on the work in two parallel small projects, namely "Sustainable Nordic Protein Production, Nordic Bio-economy" and the "Baltic Sea Region/Nordic Sustainable Protein Production Initiative – Mapping of Regional Potentials" – both financed by the Nordic Council of Ministers.

Food security and sustainability are major challenges of our time. Agriculture can provide all the biological ingredients needed for human wealth, but the food system is rather complex. In this chapter, emphasis is on regional potentials in supplying a larger part of the protein need in the Baltic Sea region with sources from agriculture. There are differences between countries and also within countries. As a whole, Europe is highly dependent on imported feed protein, and especially on soybean from South America (Masuda & Goldsmith, 2009, Hartman *et al.*, 2011, Peltonen-Sainio & Niemi 2012). On average, Europe imports 70% of the plant protein consumption, overall, and for some of the Nordic countries the number is even higher. Another estimate of the 2011 balance shows that the contributions of EU cereals and of imported soybean to the EU protein supply are of the same order of magnitude (Martin, 2014).

The European grain legume production has decreased from 4.7% of the arable land in the 1960s to less than 2% today (Buez *et al.* 2013). This decline is the result of a number of economic and policy factors as a consequence of the Blairhouse Agreement – see Box 1. A contributing factor to the protein crop decline and the increased production of cereals is a more stable yield advantage in cereals. Protein crop prices have in recent years increased slightly faster that wheat prices, imported soy feed has become more costly, and fertiliser prices are also increasing. Thus, the competitive position of legumes has improved in the last decade.

Box 1

Blair House Agreement

The GATT/WTO (Blair House Agreements 1992) allowed duty-free imports of oilseed and protein crops into EU. This caused big imports of cheap soybean products from Americas for the European livestock production, the grain legume production became unattractive to European farmers, and the research and developments followed. This is a cause of the present deficit in capacity (cultivars, cultivation methods and knowhow) to produce European protein to supply the animal production making the meat production vulnerable.

4.2 Background

Proteins are composed of amino acids and feedstuffs have different composition, determining their value for different species, different developmental stages and different type of production (meat, milk, egg or living animals). Livestock animals have different digestion and can be divided into monogastric animals (pigs and poultry and aquaculture fish) and ruminants (cattle and sheep). Ruminants digest roughage and utilise the nutrients in grass, maize, clover, hay and silage, while monogastric animals must have a compound feed, which is adapted to their specific needs, particularly the amino acid composition must be optimal, as well as the fats, carbohydrates, minerals, vitamins etc. Furthermore, nutrients must be easily digestible and not bound in coarse plant structures.

All plants contain proteins (see tables in chapter 2); forage legumes (clover and lucerne) and many grass species contain high amounts in the vegetative parts and grain legumes (soybeans, peas and beans) have high protein content in the seeds. In addition, press cakes from rapeseed oil contains high protein levels.

Soybean products are high value protein sources and are presently the preferred source of feed protein in the industry. The soybean products have high protein content and a good amino acid composition, though low in the essential sulphur-containing amino acids. Due to the oil extraction process and toasting, the anti-nutritive factors have been inactivated. In compound feed, soybean and soymeal applications are typically in the range of 15–30% of the fodder for pigs, depending on use (Jørgensen, 2012).

4.3 The Potentials

Table 7 is composed of data from different sources (indicated in the legend) and shows that soybean is not superior to other plant protein sources with respect to protein yield and other important nutritional factors. Red clover seems to be the most productive, and is high in lysine, methionine and vitamin E as well, the potentials are there, but the challenging part is how protein can be extracted and utilised for feeding monogastric animals and fish. Peas and field beans can be used without extractions (as soybean products or other grain legumes). The data in Table 7 show that field beans and peas perform even better than soybean and also here there are good opportunities.

Table 7: Yield (dry matter) and protein content in protein crops in Denmark. Soybean yield from top 20 producers in the world is approx. 2.3 t/ha

	Yield Dry matter t/ha	Protein content %	Protein kg/ha	Lysine kg/ha	Methionine kg/ha	Vitamin E g/ha
Soy Bean	2	35	700	43	9	30
Oilseed Rape	5	20	1,000	60	20	75
Pea	6	22	1,300	92	13	50
Wheat	9	11	1,000	30	16	90
Clover /grass	13	12	1,500	120	52	600
Red clover	12	21	2,600	200	90	600
Meadow grass	3	12	350	25	12	
Soy bean DEU[1]	2.5	36.8	904			
Soy bean DNK[2]	1.8	38.4	691			
Field bean[3]	4.9	28.3	1,384	86[4]	11[4]	

Source: Modified from Møller *et al*. (2005), Vitamin A data (Jensen, SK. (2014)).
Lower part is compiled from published data. 1: Vollmann *et al*. 2000, 2: Pedersen *et al*. 2009, 3: Sortsinfo 2014, 4: Feedipedia.

4.4 Regional Production

Historically, there are many plant species that have been cultivated to provide protein. Evidence of Neolithic field pea (*Pisum sativum*) cultivation in Denmark and Sweden is available (Sloth *et al.* 2012). Additionally, field bean (faba beans, *Vicia faba*), common vetch (*Vicia sativa*) and lupines (*Lupinus luteus*) were common (Westermann & Madsen-Mygdal 1902; Stoddard *et al.* 2009). Other grain legume species that have been cultivated are common bean (*Phaseolus vulgaris*), lentil (*Lens culinaris*), lupine (*Lupinus angustifolius*, *Lupinus luteolus*), and to some extent also soybean (*Glycine max*).

In addition, a large diversity of species has been cultivated for forage use or conserved forage, and today, the press meal from protein rich oil producing species like soybean, sunflower and oil seed rape are used as protein sources in compound feed mixtures.

4.5 Oilseed Rape Press Meal

Side streams of oil production in the form of soybean cakes and meal and similarly from oilseed rape and sunflower are commonly used as plant protein component in compound feed. Oilseed rape and oilseed turnip rape are grown widely in the region and the press cake is used in compound feed. Oilseed rape is a good source of high value protein with a high content of S-amino acids. This provides good possibilities for securing future protein supply in the organic sector; when the full organic feed requirement is implemented. Rapeseed meal is used as part of fish compound feed, but the application is limited by the presence of anti-nutritional factors and a relatively low protein- and energy content, which can be improved (Enami, 2011).

4.6 Grain Legumes for Feed

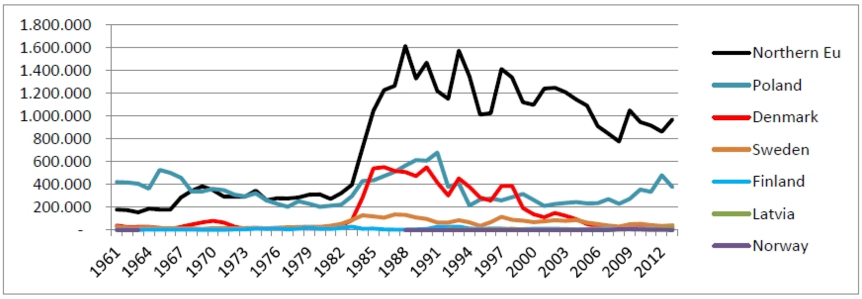
The grain legumes (also called pulses) are cultivated to maturity and the seeds are dried and used in compound feed mixtures to obtain the optimal nutritional composition for meat production. Unfortunately, the grain legumes contain anti-nutritional factors, which limit the digestibility of the feed.

Cultivating grain legumes provide advantages as the crop assimilate nitrogen from the air in symbiosis with modulating microorganisms and further leave an amount of nitrogen in the field for the next crop. This reduces the need for fertilising the field and simultaneously, it reduces the emission of greenhouse gases derived from the production and use of inorganic fertilisers. Organic farming is highly dependent on clover and other legume species for their nitrogen supply. Additionally, growing grain legumes in rotation contributes with the break effect improving disease control, nutrients and water (Griffiths, 2009).

Grain legumes also improve the soil structure by using deep rooting species (Dafa, 2012), which contributes to carbon sequestration and slow release of nitrogen in the following crop. Grain legumes show synergism in mixed cropping with cereals. In this context, the benefits of crop rotation cannot be overestimated concerning soil fertility, pest, and disease and weed control (Bugge, 2000; Griffith, 2009; Przednowek, 2004). In spite of all these positive effects, the cultivation of grain legumes has declined.

The cultivation of grain legumes in the EU has decreased from 17 mill tons in 1990 to 6 mill tons in 2013 covering 30% of the demand, in Northern Europe from 1.5 mill tons to 1 mill tons, see Figure 6.

Figure 6: The production of grain legumes (in tons) in the Northern European region of from 1961 to 2013



Source: Data extracted from FAOSTAT.

As mentioned above, this decline is the result of a number of economic and policy factors. On the farm level, the protein crop decline is attributable to a more stable yield advantage in cereals. This may be mitigated by diversifying the grain legume cultivation, thus growing genetically different species and cultivars with varying responses to cultivation conditions. Plant breeding has an important role here, both in developing cultivars well adapted to Nordic conditions for a number of protein crop species and also in making sure that the cultivars are stable under the range of climate conditions expected from climate change.

The development is also stimulated by the fact that economic agricultural decisions are taken from the farm level, which is not necessarily consistent with interest of the society. The decisions are based on higher marginal income on competing crops like wheat and maize (Visser *et al.*, 2014). If the value of ecological and society services of grain legumes were recognised, the accounts may look differently. This could be accomplished by offering incentives to farmers for cultivating grain legumes and protein crops for specific support for protein crop production as a contribution to agri-environmental practices.

4.7 Forage as Protein

The forage grasses and legumes are grown for their vegetative parts, which are consumed directly by grazing or harvested for hay or silage. These are today primarily used for ruminants. Perennial grass cultivation is a well known practice and high yielding (3–5 cuts annually) in temperate zones without any leaching of nitrogen and has the capacity to build up carbon in the soil. Grass has been recommended in the Danish "Plus 10 mio. tonnes study" as a sustainable and multipurpose crop and can produce proteins for monogastic animals (Gylling *et al.*, 2013).

Forage legumes assimilate nitrogen and are perennial species, covering the fields all year around, thus reducing leaching of nutrients, protecting and improving the soil structure and fertility. Grain legumes species may also be used as forages by harvesting them as immature green plants. It is often done in mixed cultivation with other species like cereals or grass.

4.8 Potentials in Bioprocessing

The Danish BIOVALUE SPIR innovation platform (see Box 2) and several other projects are addressing the issue of refining leaf protein concentrate from forage legumes and grasses.

Box 2

BIOVALUE SPIR, Products from Green Biomass

The overall vision is to develop a decentralised, robust and overall optimised pretreatment process for green biomass for production of animal protein feed and a storable fibre fraction that can be used as substrate on centralised biorefineries. In order to achieve viable processes on leaf protein extraction from biomass, it is crucial to integrate and optimise the whole process, e.g. wet fractionation, filtration recovery input and energy costs against product yield and quality.

The process is not yet fully developed but intensive studies and demonstrations are ongoing in Germany, Austria, Holland and Denmark. After six years of research and testing, a Dutch company (Grassa BV) was established in 2014 to exploit their technique with a mobile grass refinery.

A similar line of thoughts is behind the commercially established protein extraction for potatoes (KMC, Denmark) and is parallel to what has been shown in oil seed rape press frequently used in feedstuff today. There are large expectations to such promising green approaches utilising green biomass for livestock feed (The National Bio-Economy Panel Denmark, 2014).

4.9 Processing Protein from Forage Crops

First generation bioprocessing was directed towards the development in biogas and energy. Now, it is time to work towards an alternative protein supply. Extraction of proteins from forage legume by mechanical processing gives an easy digestible "juice" fraction of high value protein feed for monogastric animals. The remaining fiber fraction after protein extraction contains stronger bound proteins and can be fed to the ruminant livestock or used for biogas production. This approach of extracting proteins from forage crops can contribute to replace imported soybean for livestock feed. Furthermore, if the crops are optimised for this purpose, and by increasing the area of land cultivated with high protein yielding forage legumes, a higher sustainability will be reached and less nitrogen application needed. A prolonged production period and extended soil cover will reduce leaching of nutrients. The challenges in this approach are the transport of the biomass with a high water content to the processing plants and storage of the biomass before processing. However, farming systems have developed highly efficient measures on farm level to harvest and ensile grasses that could be adapted. Alternative sources of forages leaf material can be derived from sugar beets, chicory and others.

4.10 Breeding Protein Crops for the Baltic Sea Region

Availability of optimal plant cultivars is a prerequisite for a sustainable regional production of plant protein under the prevailing cultivation conditions. After 25 years of decrease in research and development of particularly grain legumes in our region, a massive action is needed to gain the lost potential to be on top of development.

The organisation of plant breeding is variable within the region ranging from purely commercial breeding companies to state owned, financed or supported institutes. Generally, all breeding has suffered drastic decrease during the past years. In the Nordic and Baltic regions, there are only a few grain legumes breeders that have survived the decline. Germplasm is available from the region and from all over the world, and there are breeding experiences and techniques from other crops available.

In the future market scenarios, there are good opportunities for regional pre-breeding of pulses and developing new adapted cultivars and maybe introducing new promising crops to alleviate the effect of anticipated climate changes. The advantages of using pulses are big in the agricultural system when the crop rotation is reintroduced. The yield instability may be mitigated by use of diverse species and/or develop more stable cultivars.

Nilsson and von Bothmer (2010) proposed a Nordic public private partnership model to collaborate on strategic crops to boost pre-breeding and development of adapted plant material for the Baltic-Nordic region. The effects of the predictable climate change are forecasted to be prominent and to proceed promptly in the northern hemisphere, especially in regions close to the Arctic (Jylhä *et al.,* 2010). Grain legumes are now bred in Finland, Estonia and initiated in Denmark, but they are not yet part of the public private partnership program. The receding commercial plant breeding has given space for micro breeders to emerge and develop cultivars of minor crops, sometimes assisted by commercial plant breeders.

The EIP-AGRI Focus Group (Schreuder & Visser, 2014) has compiled a list including advantages and challenges by each crop in breeding programs as well as the current situation of relevant breeding programs and crucial targets for European breeding of the strategic crops. Pea, faba bean, lupine species and oilseed rape press meal. With regards to further breeding activities, the proposals and recommendations in this report should be taken into consideration.

For forage legumes in traditional cultivation and for the bioprocessing approach, we must develop forage legumes with high protein content, which will grow all year, or at least can be harvested/processed all year round without losing quality, hardiness to prevailing climatic conditions in the potential marginal regions, particularly winter hardiness.

4.11 Recommendations

Aiming at increasing the local protein feed production, we should work towards independency of massive import of unsustainably produced soybean products. The application of grain legumes and forage legumes grown regionally offers a more environmentally sustainable production system of plant protein. For the Baltic Sea region, several priorities should be made:

- *Policy*: A higher degree of self-sufficiency in plant protein should be aimed for. The EU Common Agricultural Policy offers possibilities for giving incentives to diversify the crops and grow grain legumes, measures for crop diversification, environmental friendly agriculture and organic agriculture support are suitable measures.
- *Training*: Conduct workshops and establish training to educate and motivate farmers and the agricultural extension services.
- *Collaboration and networking*: Increase the collaboration and knowledge on cultivations of grain legumes, for example regarding improved agricultural practices and reintroduction of crop rotation. A good approach to do this would be to develop a regional strategic cooperation in the Baltic Sea region including stakeholders as farmers, plant breeders, livestock farmers, feed industry, food industry and retailers, including Canada/ Russia when it is relevant. Consider the establishment of a Nordic/Baltic protein center of excellence or network (comparable to the Danube Soya Initiative and similar).
- *Plant breeding*: Motivate breeders, researchers and farmers to develop improved cultivars of grain legumes and emphasise the use of different species and a range of cultivars to enhance agro-biodiversity and thus food security. Long-term public breeding programs or public private partnerships could be a good tool, as private breeding will not have the needed momentum to catch up the lost capacity during the low years. Independent of approach, long term efforts are needed since plant breeding is a long term effort. Important aims in the breeding work would be adaptation to the Nordic climate, including future climate changes and new pests, development on stable varieties well adapted to climate fluctuations and also work on reducing the nutrition inhibitors that are present in the feed proteins. The latter could be complemented with development of technological approaches. Facilitate the use of important genetic resources by establishing good characterisation and evaluation information on the germplasm stored in genebanks.

- *Innovation*: Support development of bioprocessing facilities to exploit extraction of proteins from forage legumes and their utility in feeding monogastric animals and fish. Local harvest can be suited to processing capacity, thus the storage challenge is reduced; furthermore, the large volume heavy water containing raw material must be transported shorter distances. Liquid protein solution may be used directly on the farm where compound feed mixtures are produced. This will eliminate the need for concentration.

4.12 References

Bues, A., Preißel, S., Reckling, M., Kuhlman, T., Topp, K. & Wats, C. (2013). *The environmental role of protein crops in the new common agricultural policy.* Policy Department B: Structural and Cohesion Policies. European Parliament Brussels. Retrieved from http://www.europarl.europa.eu/RegData/etudes/etudes/join/2013/495856/IPOL-AGRI_ET(2013)495856_EN.pdf (lastconsult:2014/24/04).

Bugge, J.K. (2012). *Protein crop 2000. Økologisk rapsolie er en realitet.* Dansk Videncenter for Planteolieteknologi.

Dafa (2012). *The Legumes Expert Forum; Science, economy and society – making ecosystem services from legumes competitive*. A research Strategy of the German Agricultural Research Alliance (DAFA) 07/2012. Retrieved from www.dafa.de/de/startseite/fachforen/leguminosen.html

Enami, H.R. (2011). A Rewiev of Using Canola/Rapeseed Meal in Aquaculture Feeding. *Journal of Fisheries and Aquatic Science 6*: 22–36. http://dx.doi.org/10.3923/jfas.2011.22.36

Feedipedia. *Animal Feed Resources Information System - INRA CIRAD AFZ and FAO* © 2012-2015. Retrieved from http://www.feedipedia.org/

Griffiths, J. (2009). *Legumes – benefits beyond nitrogen*. Farming Ahead No. 211 p 57. Retrieved from www.farmingahead.com.au

Gylling, M., Jørgensen, U., Bentsen, N.S., Kristensen, I.T., Dalgaard, T., Felby, C. & Johannsen, V.K. (2013). *The + 10 million tonnes study: increasing the sustainable production of biomass for biorefineries.* Report Univ. Copenhagen.

Hartman, G.L., West, E.D. & Herman, T.K. (2011). Crop that feed the world 2. Soybean – worldwide production, use, and contraints caused by pathogens and pests. *Food Security 3*: 5–17. http://dx.doi.org/10.1007/s12571-010-0108-x

Jensen SK (2014). *Livestock production at the northern margin of farming: future bio-based society.* Department of Animal Science, Aarhus University. Oral presentation.

Jylhä, K., Tuomenvirta, H., Ruosteenoja, K., Niemi-Hugaerts, H., Keisu, K., & Karhu, J.A. (2010). Observed and Projected Future Shifts of Climatic Zones in Europe and Their Use to Visualize Climate Change Information. *Weather, Climate, and Society 2*: 148–167. http://dx.doi.org/10.1175/2010WCAS1010.1

Jørgensen, L. (2012). *Sammensætning af foder. Et foder skal dække grisenes behov for næringsstoffer til vedligehold og til produktion (vækst og mælkeproduktion) og skal sikre en økonomisk optimal fodring*. Videncenter for svineproduktion (Fagligt).

Martin, N. (2014). *What is the way forward for protein supply?* The European perspective. OCL: 21 D403. http://dx.doi.org/10.1051/ocl/2014015

Masuda, T. & Goldsmith, P.D. (2009). World soybean production: Area harvested, yield, and long-term projections. *International Food and Agrobuisness Management Review 12*: 143–162.

Møller, J., Thøgersen, R., Helleshøj, M.E., Weisbjerg, M.R., Søegaard, K. & Hvelplund, T. (2005). *Fodermiddeltabel – Sammensætning og foderværdi af fodermidler til kvæg.* Rapport nr. 112, Dansk Kvæg.

Nilsson, A. & von Bothmer, R. (2010). *Measures to Promote Nordic Plant Breeding*. TemaNord 2010:518, Nordisk Ministerråd, Nordisk Råd. http://dx.doi.org/10.6027/tn2010-518

Pedersen, S.S., Kristensen, E.F., Kristensen, H.O., & Petersen, J. (2009). *Danish organic cultivation of Soybeans for food and feed – Results 2008.* The Agricultural Faculty, Aarhus University.

Peltonen-Saino, P. & Niemi, J.K. (2012). Protein crop production at the northern margin of farming: to boost or not to boost. *Agricultural and food science 21*: 370–383

Przednowek D & Regnell M (2001). Gård, åker och äng – den centrala platsens triviala bas*.* In: L. Larsson, ed. *Uppåkra. Centrum i analys och rapport. Uppåkrastudier 4. Acta Archaeologica Lundensia ser*. In 8º, No. 36. Stockholm: Almqvist & Wiksell International, pp. 113–122 (In Swedish).

Schreuder, R. & Visser, C. (2014). *The EIP-AGRI Focus Group Protein Crops: final report*. Eip_agri Agriculture and Innovation, European Commission.

Sloth, P.R., Hansen, U.L. & Karg, S. (2012). Viking Age garden plants from southern Scandinavia – diversity, taphonomy and cultural aspects. *Danish Journal of Archaeology*, 1:1, 27–38. http://dx.doi.org/10.1080/21662282.2012.750445

Sortsinfo (2014). *SortInfo*. Available online at http://www.sortinfo.dk/

Stoddard, F., Hovinen, S., Kontturi, M., Lindström, K. & Nykänen, A. (2009). Legumes in Finish Agriculture: history, present status and future prospects. *Agricultural and Food Science 18*: 191–205. http://dx.doi.org/10.2137/145960609790059578

Przednowek, D. W. A., Entz, M. H., Irvine, B., Flaten, D. N. and Thiessen Martens, J. R. 2004. Rotational yield and apparent N benefits of grain legumes in southern Manitoba. *Can. J. Plant Sci. 84*: 1093–1096. http://dx.doi.org/10.4141/P04-032

The National Bio-Economy Panel Denmark (2014). *Examples of new promising value chains. Naturerhvervsstyrelsen*. Retrieved from http://agrifish.dk/fileadmin/user_upload/NaturErhverv/Filer/Tvaergaaende/Biooekonomi/Statement_Sept2014_Appendix.pdf

Visser, C.L.M., Schreuder, R. & Stoddard, F. (2014). The EU dependency on soya bean import for the animal feed industry and potential of the EU produced alternatives. *Oilseed & fat Crops and Lipids 21*: 1–8.

Vollmann J, Fritz CN, Wagentristl H, Ruckenbauer P. (2000). Environmental and genetic variation of soybean seed protein content under Central European growing conditions. *J Sci Food Agric 80*:1300–1306. http://dx.doi.org/10.1002/1097-0010(200007)80:9<1300::AID-JSFA640>3.0.CO;2-I

Westermann, T. Madsen-Mygdal, Th. (1902). *Lectures concerning "Landbrugets Plantedyrkning: Landbrugets Kulturplanter".* Kgl. Veterinær- og Landbohøjskole, 1901–02., H. Christensens Boghandel, Copenhagen.

5. Marine Organisms' Potentials and Challenges

By *Joanna Przedrzymirska* and *Grażyna Pazikowska Sapota*, The Maritime Institute in Gdansk, Poland

5.1 Introduction

In this chapter, the following marine organisms are considered: marine macroalgae (beach cast seaweed), marine microalgae and bivalvia/clams. Crustaceans were initially considered, however, it was not possible to retrieve specific data/information about the oppertunities of cultivation of crustaceans in the Baltic Sea. The potential of freshwater microalgae is described separately in the next chapter: "Microalgae as a source for animal feed protein: Potentials and challenges." This chapter mainly focuses on the potential in the Baltic Sea region and it is based on findings of the SUBMARINER project (www.submariner-project.eu), which has been the first ever attempt made to evaluate the potential of innovative and sustainable uses of the Baltic resources. Several marine organisms investigated so far have proved to contain high protein fractions with potential use in feed. However, still large knowledge gaps need to be filled, before marine organism can become a realistic replacement for soy products. It is of importance to mention that cultivation of marine organisms has the added benefit of serving to mitigate nutrient loading and to counteract eutrophication processes.

5.2 Marine Macroalgae

There is a long tradition of using macroalgae for different purposes, such as food, animal feed and soil fertiliser. Asian countries in particular have a tradition of using algae dating back to the fourth century in Japan and the sixth century in China. While free-floating algae can be used for applications ranging from feed to bioenergy, its quality is rather low and certain end uses must be excluded. High-value macroalgae products used for human consumption, cosmetics and biotechnology are in growing demand. For those products, good macroalgae quality is required and thus cultivation is necessary. Macroalgae cultivation also has the added benefit of serving to mitigate nutrient loading and to counteract eutrophication processes. Around the Baltic Sea, a beach-cast macroalgae' biomass potential has been estimated in several locations, see Table 8.

Table 8: Estimation of beach-cast macroalgae at several locations in the Baltic Sea region

Country/location	Macroalgae (tonnes of dry weight per year)
Lithuania – Palanga beach	400
Estonia – SaaremaaIsland	1,000
Sweden – Southern regions	57,000–61,000
Poland – Sopot municipality	160–800
Denmark – Solrød municipality	13,000–24,000

Source: Schultz-Zehden, A.& Matczak, M. (eds.), (2012). *SUBMARINER Compendium. An Assessment of Innovative and Sustainable Uses of Baltic Marine Resources*. Gdańsk.

Macroalgae have high water content, are low in calories and rich in vitamins and minerals. Some species are high in digestible proteins (20–25% protein of wet weight) and the fibre content is usually higher than in terrestrial plants (Schultz-Zehden *et al*., 2012). The protein fraction of seaweed varies with the species but is generally low in brown seaweed, <15%. Higher protein contents are recorded for green and red seaweed, up to 40%. These levels are comparable to those found in high protein vegetables, such as soybeans. However, at present there is a lack of data on the chemical composition (e.g. AA, fatty acids, minerals) of many marine macroalgae with possible potential to be used as animal feed protein sources.

Currently, the ongoing project titled "Macroalgae for a biobased society, culture, biorefineries and energy extraction (SEAFARM)" aims at development of a sustainable system for the use of seaweeds as a renewable resource in the future. The transdisciplinary research approach includes techniques for cultivating seaweeds to be used as raw material in a biorefinery for the production of food, feed, biobased materials and bioenergy (http://www.seafarm.se). It is expected that results of the SEAFARM project will address one of the key knowledge gaps identified in the SUBMARINER project: identification of most suitable species and analysis of their growth in the Baltic Sea. The SEAFARM project ends in 2018.

Figure 7: Macroalgae, beach-cast on Latvian coast

Photo: Environmental Development Agency, Latvia.

Macroalgae cultivation is such a new and innovative business in the Baltic Sea region, so knowledge and expertise are very limited. The biggest challenge will probably be to find suitable macroalgae species for cultivation in brackish waters, depending on what they will be used for. After identification of specific species, functional cultivation techniques must then be developed. Given all of the environmental benefits that macroalgae cultivation can bring, there are strong indications that this could be a sustainable industry in the future. Holistic sustainability assessments are one way of integrating nature-society systems into a single evaluation. By conducting such assessment early in a process, the results can provide important information for decision-makers to judge if macroalgae cultivation projects should be promoted or not.

The largest obstacle to promoting macroalgae collection or implementing large-scale macroalgae cultivations may be to show the profitability for potential investors. From a rough economic overview, it can be concluded that direct profits in monetary terms are relatively low, but this is also the case for other biomasses used for biogas production. Therefore, the value in providing ecosystem services needs to be included in a strategic analyses. To encourage private investors in such ventures, there will be a need to make a business case, which includes the value in providing ecosystem services (e.g. nutrient trading schemes). There is also room for energy companies to run such projects for environmental goodwill.

Figure 8: Macroalgae on Latvian coast

Photo: Environmental Development Agency, Latvia.

5.3 Macroalgae Recommendations

Regarding production of macroalgae in the Baltic Sea region, we recommend:

- Projects dealing with macroalgae utilisation should be encouraged and financed to a greater extent by governmental subsidies and research funds (high negative externalities require public intervention).
- Only native macroalgae species should be considered for cultivation.
- More research is needed for further development of technologies for macroalgae cultivation, collection and processing.
- More research is needed to investigate the resource potential (including economic aspects) and environmental impact.

- Legislation adjustment to encourage macroalgae production should be undertaken.
- Discussion on nutrient trading schemes, including remediation payment rules, should be undertaken in the Baltic Sea region or the EU.

5.4 Marine Microalgae

The use of microalgae biomass has been very limited until recently. The reason for this is that naturally occurring microalgae are found in very low densities in the water, even during bloom conditions. To obtain higher microalgae concentrations for biomass production, microalgae need to be cultivated. Currently, the microalgae cultivated worldwide amounts to more than 5,000 tons of dry weight and has an approximate commercial value of EUR 1,250 million. Vast majority of this biomass is used to produce biofuel, the rest is used for high-value metabolites, such as food additives, animal feed, drugs and cosmetics (Schultz-Zehden *et al.*, 2012). One of the best-known marine microalgae is Spirulina (cyanobacteria), which has a high protein content. For more information about microalgae composition please refer to the sections: "Feed protein needs and nutritive value of alternative feed ingredients" and "Microalgae as a source for animal feed protein: Potentials and challenges" of this report.

5.5 Bivalvia/clams

These marine organisms constitute the majority of the total zoobentos biomass in the Baltic Sea. They also proved to have a high growing rate in several cultivation trials that have been carried out in the Baltic Sea region (Schultz-Zehden *et al.*, 2012). In the Gulf of Gdańsk (Szaniawska, 1991). Bivalvia/clams constitute 93.7% of total zoobentos biomass, of which *Macoma balthica* (common name Baltic macoma or Baltic clam) and *Mytilus edulis* (blue mussel) constitute 82% of zoobentos complexes' biomass. Table 9 shows the protein content of selected marine organisms according to different types of analyis. The protein content is relatively high and has the potential to be used in feed.

Table 9: Biochemical composition of the most common bivalvia species in the Gulf of Gdańsk

[% of dry weight]	*Cerastoderma glaucum*	*Mytilus trossulus*	*Macoma balthica*
Ash content	flesh: 9.7	flesh: 8.4	flesh: 5.2
Protein content (Lowry's method, only so-called "free proteins"*)	34.59	32.60	52
Protein content (Kjeldhal method)	61.70	58.97	

Source: Szaniawska, 1991.

Figure 9: Mussels cultivation installation at the sea

Photo: Odd Lindhal.

Blue mussels and other bivalve shellfish consume phytoplankton that contain nutrients such as nitrogen (N) and phosphorus (P). These marine organisms are, therefore, able to remove nutrients that are in surplus and can have a negative impact on the ecosystem. Table 10 shows an estimation of the amount of N and P that can be removed in the Baltic Sea by cultivation of blue mussels.

Table 10: Nutrient harvest potential estimates for farmed blue mussels in the Baltic Sea

	Coastal area Biomass per long line or pipe (kg/m)	Estimated harvest per ha of farm (tonnes/ha)	Mussel meat content (%)	Estimated amount N (tonnes/ha)	Estimated amount P (tonnes/ha)
Southern Baltic	35	150	30	1.8	0.12
Northern Baltic	25	100	30	1.2	0.08

Source: Schultz-Zehden *et al*., 2012.

5.6 Potential for Cultivation

Mussels may be farmed at different sites in the Baltic Sea. With regards to the selection of an optimal farming site for blue mussels (*Mytilus trossulus*), the following criteria should be met (Schultz-Zehden *et al*., 2012):

- *Hydrographical factors*, e.g. small to moderate water currents, no or infrequent occurrence of drift ice in winter, water depth of 10–30 m, salinity should not go below 4 PSU, normal bottom water exchange in order to avoid low oxygen benthic conditions.
- *Biological factors*, e.g. good to normal occurrence of mussel larvae during the settling period, good to normal occurrence of phytoplankton (mussel food), need to take marine mammal migration routes into account.
- *Legal/practical factors*, e.g. the site must be in accordance with general and local regulations on area use, the site area should be 1–10 ha, protection from heavy seas, access to the site during normal weather conditions, no discharge or other source of harmful contaminants in the close surroundings, no interference for waterways and only minor interference for recreation activities, no or minor interference for fishery, no or minor to moderate interference for residents and visitors.

These criteria need to be adjusted when applied to zebra mussel (*Draissena polymorpha*) farming site selection, mainly since zebra mussel cultivations are restricted to enclosed coastal areas (lagoons or inlets). Therefore, they should also consider: water currents suitable for effective young settlement and particulate matter uptake, not exceeding 2 m/s, much lower water depth (e.g. for the Curonian Lagoon the suitable water depth is considered less than 2 m due to shallowness of the zebra mussel natural habitats),salinity should not exceed 1.5 PSU with no or minimum abrupt salinity fluctuations.

It is presently not possible to make a reliable estimate of how many sites and how big the total area that may potentially be available for mussel farming along the Baltic coasts that meets the criteria given above. For blue mussels the possibility of utilising areas used for wind power generation may be an additional possibility, especially in view of the technical possibility of lowering the mussel nets. This concept should be further explored.

Mussel farming has the potential to be a sustainable means of combating eutrophication provided it is part of an integrated management plan, which includes remediation measures addressing nutrient inputs at their source and recycling of nutrients by using mussel harvest for feed production and fertiliser. Furthermore, there is a need to address at a political level, the issue of compensation for ecosystem services. Given the above, mussel farming may become a new commodity and a commercially promising area for entrepreneurship, creating new businesses and jobs in rural coastal areas.

Figure 10: Collection of experimental mussels cultivation

Photo: Odd Lindhal.

There is a growing interest in using Baltic mussels for feed production and fertiliser. A risk assessment of farmed mussels from the Kalmarsund area in Sweden has clearly demonstrated that the concentrations of toxic elements and organic contaminants in the soft tissue and the shells are safely below the regulatory limits for use in both feed and fertiliser. Production of mussels for these end uses may thus have a substantial potential for growth. Especially the interest in making feeds based on Baltic Sea raw materials is increasing and feed trials with rainbow trout and arctic char are ongoing. Further, feed trials on organic livestock of pig, layers and chicken, where mussel meal of Baltic origin is used as a high quality protein source (replacing fishmeal) will be carried out during autumn 2012.

Current technologies such as the use of nets or long-lines as substrate for settling and growth seem to already work well for mussel farming in the Baltic Sea, though future mussel farms in the region will have to be able to manage ice during winter, especially drifting ice.

There are still a number of knowledge gaps concerning mussel farming in the Baltic Sea, the most critical of which are: assessment of legislation issues related to the implementation of mussel farming for water quality remediation in the different Baltic countries, innovative and suitable for the Baltic conditions technologies and technics (installations, harvesting, logistics), in-depth knowledge on growth rate under different physical environmental conditions, cumulative ecological impact assessment (including sediments), in depth cost-benefits analysis.

5.7 Bivalvia/clams Recommendations

It is recommended to further support the technical development of farming mussels in the Nordic countries and in the Baltic Sea region as an environmental measure for improving coastal water quality, as well as for the important recycling of nutrients according to the Agro-Aqua nutrient recycling principle. A robust and sustainable system for financing and paying for the nutrient recycling enterprises is absolutely necessary if mussel farming and similar eutrophication abatement methods should become a reality.

5.8 References

Szaniawska, A. (1991). *Gospodarka energetyczna bezkręgowców bentosowych występujących w zatoce Gdańskiej*. Wydawnictwo Uniwersytetu Gdańskiego: Gdańsk.

Schultz-Zehden, A. & Matczak, M. (eds.) (2012). SUBMARINER Compendium. *An Assessment of Innovative and Sustainable Uses of Baltic Marine Resources.* Pp. 055, 130, 081, 087, 092.

SEAFARM project website: http://www.seafarm.se.

Ocean Harvest Technology, company website http://oceanharvest.ie

Helland, S., Terjesen, B.F. & Berg, L.(2003). Free amino acids and protein content in the planktonic copepod Temora longicornis compared to Artemia franciscana. *Aquaculture 215*, pp. 213–228. http://dx.doi.org/10.1016/s0044-8486(02)00043-1

6. Microalgae as a Source for Animal Feed Protein: Potentials and Challenges

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6.1 Introduction

Microalgae compose an enormous and diverse group of one-celled organisms with a size ranging from 5–50 µm. The small size gives them a large relative surface where photosynthesis and nutrient uptake takes place (Hein *et al*., 1995). Many microalgae are able to reach very high growth rates. Cultures with doubling times as low as 3.5 h. have been reported (Spolaore *et al*., 2006), (Chisti, 2007). Obviously, these interesting primary producers represent a great potential as a source for future production of protein-rich animal feed, for example.

6.2 The Protein Content and Quality of Microalgae

The protein content of microalgae varies considerably. Some species can reach protein content as high as 60–70% of their dry matter (Becker, 2007). A high content of crude protein is one thing – however, the quality of the protein is of crucial importance. Protein quality and digestibility are important factors when considering the applicability of the biomass as animal feed. Recent Australian research has indicated that species of the algae *Scenedesmus sp.* prove suitable as animal feed (Duong *et al*., 2015). Experiments, where various types of microalgae biomass was fed to weanling pigs, broiler chicks and laying hens, indicated that this protein source is suitable for replacing 7.5–15% of the dietary soybean meal and corn. A replacement with microalgae biomass exceeding 15% of the soybean meal may, however, cause complications. These complications may be due to the high ash content of some microalgae, which is likely to cause imbalances of the blood plasma – affecting the gastro intestinal tract and hence the weight gain of the animals (Gatrell *et al*., 2014), (Leng *et al*., 2014). However, this disadvantage is likely to be related to the choice of algae species used and the use of more suitable algae strains should, therefore, be investigated.

The composition of phytonutrients of microalgae biomass is highly variable depending on various growth parameters such as: nutrient concentrations, light intensity and temperature. However, this plasticity specifically relates to the variation of various types of fatty-acids, antioxidants and vitamins. With regards to the protein quality of the microalgae, it appears that the amino acid profile is quite steady and only little affected by growth parameters. In fact, the amino acid composition among different species of green microalgae seems to be very similar (Guedes & Malcata, 2012).

Generally, the composition of essential amino acids in microalgae is quite similar to that of soy protein – currently the dominating protein source in both swine and poultry feed (Becker, 2007). In addition, the content of essential amino acids appears to meet the nutritional requirement of monogastric animals (Smith *et al*., 2014). Especially lysine and methionine, which are the most limiting dietary amino acids are well represented in many microalgae (Lum *et al*., 2012), (Becker, 1994).

Research evaluating the nutritional safety of the green algae *Chlorella vulgaris* proved this as a safe source of feed protein, when tested in both humans and rats (Janczyk *et al*., 2005), (Moo-Young & Gregory, 1986).

Thus, regarding protein quality, it would make sense to focus on microalgae-derived proteins for feed purposes in the future. It is also important to stress that microalgae, aside from the high protein content, contain large quantities valuable omega-3 polyunsaturated fatty acids (PUFAs) – another great advantage when considering its suitability for animal feed.

Microalgae production based on local species grown in nutrient-rich side streams is likely to be dominated by various species of the green algae *Scenedesmus sp.* Preliminary results from the ongoing project "Green Pigs/Grønne Grise" AgroTech Denmark, show that microalgae (see Figure 11) grown on nutrients from the ventilation air from swine stables can reach a protein content as high as 54% (dry matter). However, this algae is not only known to be protein-rich, but also to have a notoriously strong cell wall. This is of crucial importance when considering the use of this algae species as a feed resource in the future as the digestive enzymes access to the cell content is impaired by the strong cell wall (Han & McCormick, 2014). However, by choosing the right type of processing, the digestibility of the crude algae protein can be increased considerably. Especially ultrasonic treatment seems to have a positive effect on breaking the cell wall (Janczyk *et al.*, 2005).

Figure 11: Mixed algae culture from the bioremediation project: "Green pigs" AgroTech, Denmark, 2015

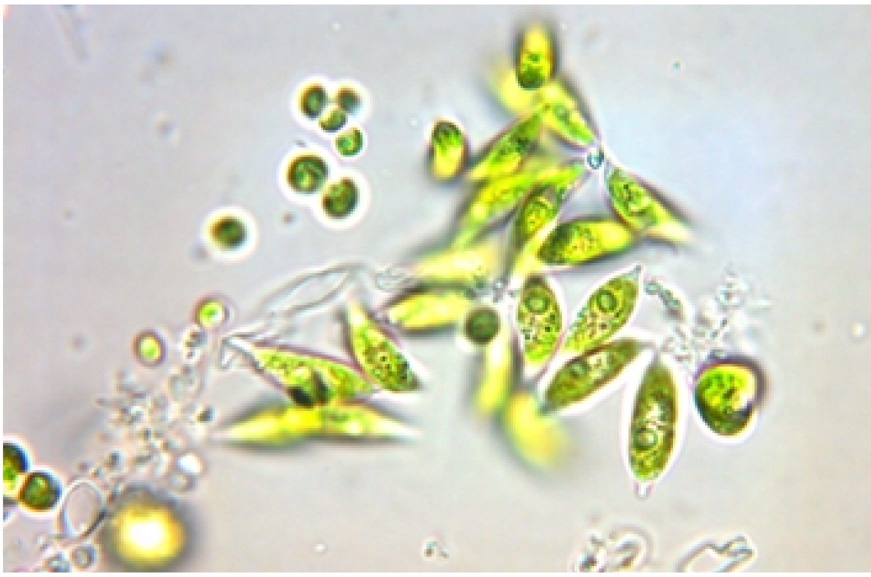


Photo: AgroTech, Denmark.

6.3 Benefits of Microalgae Protein Production

Major benefits can be linked to a future application of microalgae in animal feed. If the algae biomass is cultured in agricultural side streams there will also be a financial saving on fresh water and chemical fertiliser use.

Our ever-increasing global population requires that crops are used directly as food and not for feed. Microalgae biomass cultured on various side streams is a perfect alternative as a feed ingredient and the cultivation of microalgae does not necessarily require arable land.

6.4 Challenges and Barriers

A number of challenges and barriers has been identified with regards to production of microalgae for feed purposes. These include:

- Harvesting: removing the very small microalgae cells from the media is a major challenge. There are several ways to harvest microalgae. Flocculation followed by sedimentation has proven to be an effective and economic method of harvesting (Chen *et al.*, 2013).
- The risk of contamination with toxin-producing pathogens.
- Intensive zooplankton grazing on the microalgae. Some protein will be lost – some will be converted into invertebrate protein often suitable as protein-rich animal feed (Bogut *et al.*, 2007).
- The risk of not accommodating novel feed special requirements.

6.5 Summary

Microalgae with a high content of feed quality protein can without doubt be produced locally in the geographical area of the Baltic Sea region. By integrating the algae production into existing infrastructures with surplus heat, CO_2 and nutrients, the algae production can be sustained throughout most of the year.

Harvesting is still one of the greatest challenges. The potentially large growth rate of microalgae is proportional to the harvesting rate, which also needs to be cost effective. The application of flocculation is a suggested solution to this challenge.

This synopsis focuses exclusively on the possibility of substituting imported (soybean) protein with locally produced proteins within the Baltic Sea region. However, this prospect is inextricably linked to the potentials of an extensive industry focused on a comprehensive biorefinery concept. Estimating the feasibility and profitability of microalgae derived feed protein will only currently make sense as a component of a more complex and integrated system, which addresses the multifunctional potential of microalgae as a tool for remediation purposes and environmental emission control.

The relatively new field of microalgae technology is an area with intense research and development requirements, motivated by a variety of issues and potentials. Thus, we are confident that a variety of production techniques of microalgae feed proteins will be available for implementation in the near future.

6.6 Recommendations

- In order to minimise production costs and energy resources, locally derived algae strains, which are naturally adapted to the climate of the geographical production region are recommended.
- The integration of microalgae production with biogas plants, which can have multiple benefits such as the reduction of flue gas emissions/CO_2 and using excess heat during cold periods.
- For the choice of algae media, focus should be on nutrient rich side streams where possible.
- More research in identifying microalgae properties for specific high-value component content in algae biomass is recommended in view of future bio-refinery potentials.
- Further test and development of continual large scale algae cultivation and harvest technology.
- Existing regulations regarding use of a new raw material such as fresh microalgae biomass should be reviewed and updated accordingly.

6.7 References

Becker, E. (1994). *Microalgae: biotechnology and microbiology*. Cambridge University Press. http://dx.doi.org/10.1016/j.biotechadv.2006.11.002

Becker, E. (2007). Microalgae as a source of protein. *Biotechnology advances, 25*(2), 207–210.

Bogut, I., Has-Schøn, E., Adamek, Z., Rajkovic, V., & Galovic, D. (2007). Chironomus plumosus larvae - a suitable nutrient for freshwater farmed fish. *Poljoprivreda Agriculture, 13*(1), 159–162.

Chen, L., Wang, C., Wang, W., & Wei, J. (2013). Optimal conditions of different flocculation methods for harvesting Scenedesmus sp. cultivated in an open-pond system. *Bioressource technology, 133*, 9–15.

Chisti, Y. (2007). Biodiesel from microalgae. *Biotechnology advances, 25*(3), 294–306. http://dx.doi.org/10.1016/j.biotechadv.2007.02.001

Duong, V., Ahmed, F., Thomas-Hall, S., Quigley, S. N., & Schenk, P. (2015). High protein and high lipid producing microalgae from Northern Australia as potential feedstock for animal feed and biodiesel. *Frontiers in Bioengineering and biotechnology, 3*, 53. http://dx.doi.org/10.3389/fbioe.2015.00053

Gatrell, S., Lum, K., Kim, J., & Lei, X. (2014). Non-ruminant nutrition symposium: Potential of defatted microalgae from the biofuel industry as an ingredient to replace corn and soybean meal in swine and poultry diets. *Journal of animal science, 92*(4), 1306–1314. http://dx.doi.org/10.2527/jas.2013-7250

Guedes, A., & Malcata, F. (2012). Nutritional value and uses of microalgae in aquaculture. I Z. Muchlisin (Red.), *Aquaculture*. InTech.

Han, K., & McCormick, M. (2014). Evaluation of nutritive value and in-vitro rumen fermentation gas accumulation of de-oiled algal residues. *Journal of animal science and biotechnology, 5*(1), 31. http://dx.doi.org/10.1186/2049-1891-5-31

Hein, M., Foldager Pedersen, M., & Sand-Jensen, K. (1995). Size-dependent nitrogen uptake in micro and macroalgae. *Marine ecology progress series*(118), 247–253. http://dx.doi.org/10.3354/meps118247

Janczyk, P., Wolf, C., & Souffrant, W. (2005). Evaluation of nutritional value and safety of the green microalgae Chlorella vulgaris treated with novel processing methods. *Archiva Zootechnica, 8*, 132–147.

Leng, X., Hsu, K.-N., Austic, R., & Lei, X. (2014). Effect of dietary defatted diatom biomass on egg production and quality of laying hens. *Journal of animal science and biotechnology, 5*(3). http://dx.doi.org/10.1186/2049-1891-5-3

Lum, K., Kim, J., & Lei, X. (2012). Dual potential of microalgae as a sustainable biofuel feedstock and animal feed. *Journal of animal science and biotechnology, 4*(1), 53.

Moo-Young, M., & Gregory, K. (1986). *Microbial biomass proteins*. Springer Science and Business Media.

Smith, J., Gerrrard, C., Nelder, R., Clements, R., & Pearce, B. (2014). *100% organic feed for poultry - Results of feed trials in the UK*. ISOFAR, Johann Heinrich von Thünen-Institut.

Spolaore, P., Joannis-Cassan, C., Duran, E., & Isambert, A. (2006). Commercial applications of microalgae. *Journal of bioscience and bioengineering, 101*(2), 87–96. http://dx.doi.org/10.1263/jbb.101.87

7. Protein from Forest Sidestreams and Other Sources

By *Ragnar Jóhannsson*, Matís ohf., Iceland

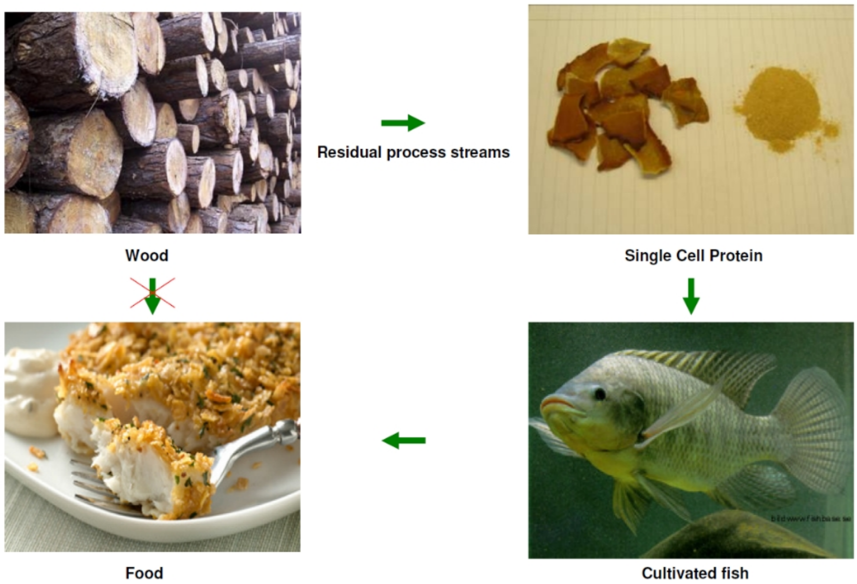
7.1 Introduction

Fishmeal is the dominant protein source in fish food, but its production is decreasing since better utilisation of pelagic fish directly into more valuable human food products is envisaged with better techniques in fishing and chilling of the raw materials (Tacon and Metian 2013). The expected shortage in protein has to be met with alternative protein sources, which need to be economically and environmentally sustainable, high quality and not compete with human food production (Ferouz *et al.,* 2010, Lim *et al.*, 2008 (eds.)). However, most available protein sources are of plant origin and they can, in general, only be used in limited amounts due to a different amino acid composition compared to fishmeal protein and the presence of anti-nutritional substances that can be detrimental for the fish (Enami 2011, Espe, *et al.*, 2012). An interesting alternative is Single Cell Protein (SCP). SCP consists of microorganisms such as yeast, bacteria, algae and filamentous fungi. Many species have high protein content and some have amino acid profiles that are very similar to that of fishmeal. In addition, SCP can be produced using residual stream from the forest industry or other sources. This offers an attractive concept of turning forest raw material and other resources into a protein-rich component in fish feed.

7.2 Protein from Microorganisms

An EU/Eurostar project (Microfeed) focused on producing Single Cell Protein (SCP) from forest industry side streams recently finished (Alrikson *et al.*, 2014). The project's main aim was to develop a replacement product for fishmeal. The focus was to choose, which microorganisms would be best suited and which site streams in the cellulose and paper industry would be best suited for the production of SCP.

Figure 12: The principle "From wood to food"



Source: Fish feed from wood. Presentation by Alriksson *et al.*, 2013. Processum.

The idea of producing SCP from industrial side streams is in fact nothing new. During the First and Second World Wars, some research went into producing SCP, although primarily as a human food (Jorge *et al.*, 2012, Silva, 1995, Romantschuk, 1976). The reason that the SCP concept would work today, when it failed before, is the current eco-awareness, combined with the sharp price rises caused by the prospect of the protein raw material, i.e. fish, running out or used directly for human consumption.

There have been other experiments, with mixed results, in which the fish proteins were replaced with soy protein, for example. The benefit of SCP is that the protein from microorganisms such as bacteria, yeasts, algae and filamentous fungi, are closer to animals and humans than protein profile from plants such as soy are. They also reproduce and double their populations very quickly. Increasing population is more depended on several factors such as media, volume of the reactor, reactor performance and other key growth parameters. Therefore, it is possible to achieve the amount of product to be increased equal to a ton or more within a day time under optimized condition. A couple of kilos of microorganisms can grow to a weight of several tonnes in a day.

7.3 The Production of SCP from Pulp Mills

The Nordic pulp and paper industry has traditionally been very strong but today it suffers from decreasing demand of their products and tough competition from Asia and South America. Development of new innovative products from wood, such as feed, is essential for the competitiveness and survival of the Nordic forest industry.

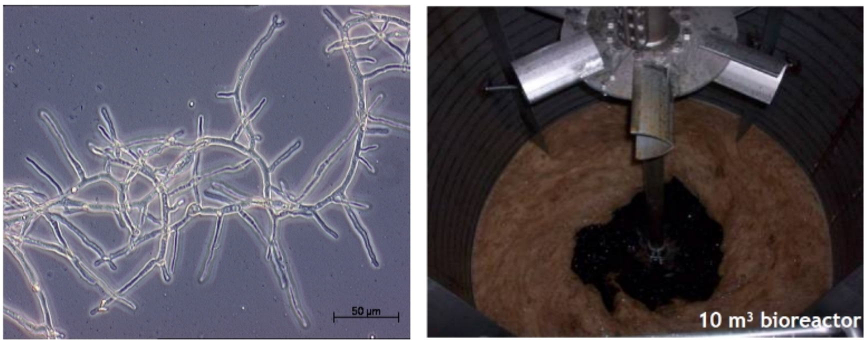
Spent sulfite liquor (Figure 13) is produced in large amounts and a single mill can generate about 250 m^3 per hour. Commercial attempts to produce SCP from spent sulfite liquor has also previously been carried out but there are no plants in operation today (Ugalte, 2002).

Figure 13: Pulp mill side streams. Left: Fiber sludge. Right: Pulp mill liquor

Source: Fish feed from wood Presentation by Alriksson *et al.*, 2013, Processum.

This side stream is now used for the production of biogas. The biogas has a relative low value compared to animal protein such as fishmeal. The value of each sugar unit converted to proteins is around 1 EUR/kg (protein price 1.6 EUR/kg and est. yield 60%) whereas the value converted to biogas is about 0.45 EUR/kg (gas price 0.75 EUR/kg and yield est. about 55%). Therefore, the value increase per sugar unit is a factor two. In addition, it enables the production of best available fish feed for production of high-end fish products suitable for local food markets with synergetic impact. This use of side steams in cellulose industry is innovative. In addition, it enables the production of best available fish feed for production of high-end fish products suitable for local food markets, which in turn has much more synergetic impact than biogas production.

Figure 14: Production of SCP. Left: Filomentous fungi. Right: Biorector with culture of Filomentous fungi



Source: Fish feed from wood. Presentation by Alriksson *et al.*, 2013, Processum.

Co-production of SCP in a biorefinery (e.g pulp mill) could be a reality within a few years and result in about 10–20 jobs per production plant and generate a turnover of EUR 25–50 million. A greenfield plant dedicated for production of SCP is projected to generate about 50–200 new jobs and a turnover of EUR 50–100 million. The annual fishmeal production is about 5–6 million tons. Sweden alone has about 35 pulp mills, which gives a potential in the range of 1–2.5 million tons of SCP per year (Alriksson 2015). This protein alone would be sufficient for the production of 0.5–1.2 million tons of salmon. Since the amino acid composition of the SCP is equivalent to fishmeal and usually more than half of the protein demand can be met with plant protein, twice the amount of salmon could be effectively produced. As seen in Table 11 below, the countries in the Baltic region including Germany have in total around 100 paper mills. It can, therefore, be concluded that the production of SCP can serve as a noteworthy protein source for fish feed production.

Table 11: Paper mills in the Baltic Sea region

Country	Number
Finland	30
Sweden	35
Denmark	9
Norway	9
Poland	4
Germany	19
Sum	106

Currently there is no commercial production of SCP in the Nordic/BS region only pilot scale located at the Technical University of Denmark. In Denmark however Unibio is planning industrial scale production of SCP in in 2016/2017 (Larsen, 2015). Production is based on methane (natural gas) as substrate and 20–30 new jobs are expected. The microorganism double every 5th hour and has a high protein content >70%. Unlike algae, the microorganism does not rely on photosynthesis and SCP can be produced all year round in bio-reactors, independent of wind and weather, not occupying already farmed area. The amino acid profile can be tailored by using different production parameters and the extend is currently being investigated as part of a project funded by Innovations Fund Denmark.

7.4 Recommendations

Production of SCP from wood biorefineries can be a feasible alternative to fish proteins, especially when produced from filamentous fungi. Such a local feed production will increase food security and work towards independency of massive import of fish and soy meal. The application of SCP production regionally offers a more environmentally sustainable production system of protein. Biorefineries in many cases offer infrastructure for fish production (water, power, effluent treatment) and can, therefore, offer good basis for locally produced fish. For the Baltic Sea region, several priorities should be made:

- *Policy*: A higher degree of self-sufficiency in protein should be aimed for. Measures should be taken to facilitate the production of SCP in biorefinaries, possibly linked with support to local aquaculture production. The aquaculture could be benefiting from other resources avalible in biorefinaries (water, rest heat etc.).
- *Training*: Conduct workshops and establish training to educate and motivate biorefinaries and potential local fish producers and processers.
- *Collaboration and networking*: Increase the collaboration and knowledge on SCP production and on Recirculation Aquaculture Technologies (RAS) for the production of fish close to biorefinaries. A good approach to do this would be to develop a regional strategic cooperation in the Baltic Sea region including stakeholders as biorefinaries, fish farmers, poultry producers, feed industry, food industry and retailers, including Canada/Russia when it is relevant.

Consider the establishment of a Nordic/Baltic SCP protein center of excellence or network.

- *Innovation*: Support development of bioprocessing facilities to produce SCP and their utility in feeding monogastric animals and fish. Local production can be suited to local aquaculture.

7.5 References

Alriksson, B. (2015). Personal communication.

Alriksson, B., Hörnberg, A., Gudnason, A., Knobloch, S., Arnason, J. & Johannsson, R. (2014). *Fish feed from wood. Cellulose Chem. Technol.* 48 (9–10), 843–848.

Enami H.R, (2011). *A Review of Using Canola/Rapeseed Meal in Aquaculture Feeding.* Journal of Fisheries and Aquatic Science, 6: 22–36. http://dx.doi.org/10.3923/jfas.2011.22.36

Espe, Marit, El-Mowafi, Adel & Ruohonen, Kari (2012). *Replacement of Fishmeal with Plant Protein Ingredients in Diets to Atlantic Salmon (Salmo salar) – Effects on Weight Gain and Accretion, Aquaculture*. Dr. Zainal Muchlisin (Ed.), ISBN: 978-953-307-974-5, InTech, Retrieved from http://www.intechopen.com/books/aquaculture/replacement-of-fishmeal-with-plant-protein-ingredients-in-dietsto-atlantic-salmon-salmo-salar-effec

Ferouz, Y., Ayadi, Kurt, Rosentrater, A., & Kasiviswanathan Muthukumarappan, (2012). Alternative Protein Sources for Aquaculture Feeds. *Journal of Aquaculture Feed Science and Nutrition, 4*: 1–26. http://dx.doi.org/10.3923/joafsnu.2012.1.26

Jorge, A.F., Lennartsson, P.R., Niklasson, C., Lundin, M., Edebo, L., & Taherzadeh, M.J. *BioResources*, 7, 173 (2012).

Larsen, H.B. (2015). Personal Communication.

Lim, C., Lee, C.S. & Webster, C.D. (Eds.) (2008). *Alternative Protein Sources in Aquaculture Diets.* CRC Press, ISBN 9781560221487.

Romantschuk, H. *Continuous culture 6: applications and new fields*, edited by A. C. R. Dean, D. C. Ellwood, C. G. T. Evans and J. Melling, published for the Society of Chemical Industry, London 1976, pp. 116–121.

Silva, J.B.A., de Mancilha, I.M., Vannetti, M.C.D. & Teixeira, M.A. *Bioresource Technol*, 52, 197 (1995). http://dx.doi.org/10.1016/0960-8524(95)00029-E

Tacon, A. G. J. & Metian M. (2013). Fish Matters: Importance of Aquatic Foods in Human Nutrition and Global Food Supply. *Reviews in Fisheries Science Vol. 21*, Iss. 1. http://dx.doi.org/10.1080/10641262.2012.753405

Ugalte U.O. and Castrillo, J.L. (2002). *Single Cell proteins from Fungi and Yeasts*. Applied Mycology and Biotechnology, Vol 2 Agriculture and Food production. Elservier 2002. Page 131.

8. Protein Value Chain – Insects

By *Ragnar Jóhannsson* and *Birgir Örn Smárason*, Matís ohf., Iceland

8.1 Introduction

If predictions hold, by 2050 the world will host 9 billion people, which could mean that current food production will need to double. This will put a strain on external proteins sources as well as natural resources in general and environmental and social aspects have to be considered. From a Nordic and European perspective, a large proportion of the protein demand is met with soy protein from South America. The production of soy in rain forest areas raises environmental concerns and with increase in demand, prices will subsequently rise. This affects the availability of protein for our animal production. We need to re-evaluate what we eat and how we produce it. Inefficiencies need to be rectified and food waste reduced. We need to find new ways of growing food.

Insects have been a part of human diet through the ages. Today, it is believed that insects are part of the direct diet of 2 billion people. Insects are often considered a nuisance to human beings pests for crops and animals. In fact, insects provide food at low environmental cost, contribute positively to livelihoods and play a fundamental role in nature. These benefits are largely unknown to the public. Although the majority of edible insects are gathered from forest habitats, innovation in mass-rearing systems has begun in many countries. Insects offer a significant opportunity to merge traditional knowledge and modern science in both developed and developing countries.

Insect rearing for food and feed remains a sector in its infancy and the science of edible insects is still at a relatively pioneering stage but advancing fast. Key future challenges will emerge such as rising costs of animal protein, food and feed insecurity, environmental pressures, population growth and increasing demand for protein. Thus, alternative solutions to conventional livestock and feed sources urgently need to be found (van Huis, *et al.*, 2013).

8.2 Insects as Feed

In 2011, combined world feed production was estimated at 870 million tonnes with revenue from global commercial feed manufacturing generating approximately USD 350 billion globally. FAO estimates that production will have to increase by 70% to be able to feed the world in 2050. Despite this, little has been said about the opportunities insects offer as feed sources. At present, ingredients for both animal and fish feed include fishmeal, fish oil, soybeans and several other grains.

A major constraint to further development are the prohibitive costs of feed, including meat meal, fishmeal and soybean meal, which represent 60–70% of production costs. Another problem is manure disposal, which is becoming a serious environmental problem; it is not uncommon for large amounts of manure to be stockpiled in open-air lots, swarming with flies (van Huis, *et al.*, 2013).

Invertebrates have been confirmed as valuable feedstuff for fish through ongoing research since 1950's, although it is not commercially widespread. *Hermetia* illucens *or* the Black solder fly (BSF), see Figure 15 has been studied for the last decades although transformation of organic waste by the BSF is a relatively new practice. Available studies indicate that complete or partial replacement of fishmeal and fish oil with BSF will take place in the coming years, especially in the light of decreasing fishmeal supplies (Sheppard *et al.*, 2008).

Figure 15: Black solder fly (Hermetia illucens) in fly stage (A) as pupa (B) and in the larval stage (C)

Photo: Stephen Knobloch, Matis, Iceland.

The Black soldier fly is found throughout the Western Hemisphere and is a wasp like fly of the genus *Stratiomyidae,* which thrives in warm places. The fly is completely harmless, does not have a stinger or any mouth functional parts. It does not consume or regurgitate on human food in its adult stage and is, therefore, not associated with transmission of diseases (Björnsson, 2012). The larva mainly consumes decaying organic matter such as rotting fruits and vegetables, animal manure and spoiled feed (Newton & Sheppard, 2004).

By taking advantage of available nutrients and water, the larvae can reduce the amount of substrate they are grown on by 50–95%, making the benefits of their use substantial in relation to resource utilisation and environmental impacts. The environmental benefits of rearing insects for food and feed are founded on the high feed conversion efficiency of insects compared to cattle or pigs for example, and are reported to emit fewer greenhouse gases and less ammonia. In addition, insects can be reared on organic side-streams (including human and animal waste) and can help reduce environmental contamination.

Recent high demand and consequent high prices for fishmeal/soy together with increasing aquaculture production is pushing the development of insect protein for aquaculture and poultry. Insect-based feed products have a similar market to fishmeal and soy, which are presently the major components used in feed formulae for aquaculture and livestock. Available evidence suggests that insect-based feeds are comparable with fishmeal and soy-based feed formulae.

8.3 Environmental Opportunities

The inevitable pressure foreseen on already limited resources such as land, oceans, fertilisers, water and energy call for immediate actions. Agriculture, and specifically livestock production, contributes heavily to GHG emissions and other environmental impacts such as deforestation. With global demand for livestock products expected to more than double between 2000 and 2050 and fish production and consumption increasing dramatically in the last five decades, meeting this demand will require innovative solutions. The aquaculture sector has boomed and now accounts for nearly 50% of world fish production. The sustainable growth of the sector will depend largely on the supply of terrestrial and aquatic plant-based proteins for feed. The opportunity for insects to help meet rising demand in meat products and replace fishmeal and fish oil is enormous (van Huis, *et al.*, 2013).

Consuming insects has a number of beneficial advantages for production and the environment. They have high feed-conversion, they can be reared on organic side streams, reducing environmental contamination, while adding value to waste. They emit relatively few GHGs and relatively little ammonia.

Figure 16: Insect rearing

Note: Left: Culture bucket with larvae.
Right: Corrugated cardboard with egg deposits.

Photo: Stephen Knobloch, Matis, Iceland.

8.4 Industrial Production

In temperate countries, processing technology is virtually non-existent because edible insects are not recognised food and feed sources. If insects are to become a useful and profitable raw material in the food and feed industries, large quantities of quality insects will need to be produced on a continuous basis. This requires the automation of both farming and processing methods, which remains a challenge for the development of the sector (van Huis, *et al*., 2013).

The concept of farming insects for food and feed is new but is gaining a foothold. A few industrial-scale enterprises all around the world are in various start-up stages of rearing mass quantities of insects such as Black soldier flies. In May 2014 work began on the world's largest fly farm, the USD 11m investment backed AgriProtein factory in Cape Town, South Africa. Some experts say that this consept could revolutionise the animal feed sector by producing a feed 15% cheaper than fishmeal. The waste-to-protein process used involves over eight billion flies producing protein rich larvae fed on organic waste. Canadian feed corporation Enterra now produces high protein insect meal for use in feed products made from up-cycling of organic waste. They are currently scaling up to processing capacity of 100 tons per day and deliver 6 tons of feed and 8 tons of fertilisers as a co-product per day. This adds up to 2,000 tons production of protein per year. The main raw materials for both these companies are human food discards and discarded fruits and vegetables. These are effectively utilised as substrate by BSF larvae but other insect larvae can be used. Human food discards and discarded fruits and vegetables represent a huge amount of organic waste today as about roughly one third of the food produced in the world for human consumption every year – approximately 1.3 billion tons – gets lost or wasted according to the United Nations Environmental Programme (UNEP).

The Netherlands is developing an innovative supply chain that includes large-scale insect farming and marketing the insect-derived products for food and feed. Research institutes are supporting this development process. The principles of the circular economy and theories on environmental economics are based on an interrelationship between the environment, economics and the future scarcity of sufficient, nutritious and healthy food. The design of the insect supply chain is circular. It is based on farming insects on organic waste and using the insects as a food or feed ingredient. This takes place against a background of growing demand for animal protein, the negative side-effects of conventional meat production and the increasing problem of waste disposal. Supply-chain partners, knowledge institutes, NGOs and national and regional governmental bodies have a roadmap for creating a prosperous insect industry by 2020. The aim for 2020 is to introduce farmed insects as ingredients for feed and food (van Huis, *et al.*, 2013).

In a recent collaboration between Ragnsells, Sweden and the Swedish Agricultural University, SLU, trial processing of organic waste materials from companies and households are projected. Initial size will process 3,000 tonnes of raw material per year. If this proves to be succesful, hundred thousand tonnes of raw material is available.

8.5 Opportunities in the Nordic and Baltic Countries

Since 2005 it is not allowed to landfill organic waste in Sweden. This means that recycling of organic waste is promoted and the capacity of biological treatment is increasing. About 60% of the Swedish municipalities have separate collection of food waste (households, restaurants, food stores, schools and similar businesses with central treatment). Waste from the food industry, slaughterhouses, etc. is not included. Furthermore, in Sweden 370,070 tons food waste and about 45,000 tons slaughterhouse waste was recovered in 2013. It goes to composting plants or biogas production. These about 400,000 tons could potentially be utilised for the production of 25,000 tons insect protein meal at the price of 1,500 USD/ton of a total value of 35 million USD and 28,000 tons of fertiliser of a value of 8–10 million USD.

In Norway, according to national statistics, 62 centralised biological plants treated 400,000 tons of organic waste (including sewage sludge treated off site and amendment) in 2011. Composting is still the predominating technology, only 62,000 tons were treated in anaerobic digestion plants.

Anaerobic digestion (AD) has a long tradition in Denmark in particularly for pig slurry, manure and sewage. The Danish Ministry of Energy counts on a tripling of energy from biogas in 2020. This energy increase is primarily considered to be reached by agricultural residues, but to make the manure based plants feasible, more energy rich fractions like biogenic organic household waste is needed, since food industry waste is already used to a large extend at the farm driven AD plants.

The use of insects to transform these waste streams into raw materials suitable to be used in fish feed thus represent an important contribution to future growth possibilities of meeting the feed required for the future growth of aquaculture.

8.6 Recommendations

Production of insect protein has a good potential in the Nordic/Baltic region due to advanced waste handling systems. Aiming at increased food security and better use of natural resources, we should work towards diversification of production of proteins with suitable amino acid profile. The application of insect protein production produced regionally offers an environmentally sustainable production system and utilises well organised waste collection systems in the Nordic/Baltic region. For the Baltic Sea region, several priorities should be made:

- *Policy*: Work on regulations regarding the production of insect proteins should be finalised as soon as possible. A safe and nutritious insect protein for mono gastric animals should be aimed for. Measures for insect production, environmental friendly agriculture, and organic agriculture and aquaculture support are suitable measures.
- *Training*: Conduct workshops and establish training to educate and inform on risk/benefits motivate potential companies, feed producers, farmers (including fish farmers) and the general public.
- *Collaboration and networking*: Increase the collaboration and knowledge on cultivations of insects as an example regarding roles and regulations and necessary production practices. A good approach to do this would be to develop a regional strategic

cooperation in the Baltic Sea region including stakeholders as farmers, feed companies, waste management companies, and retailers. Consider the establishment of a Nordic/Baltic protein center of excellence or network.

- *Innovation*: Support development of bioprocessing facilities of insect protein production and their utility in feeding monogastric animals and fish and for food purposes bigger units.

8.7 References

Becker, E. (1994). *Microalgae: biotechnology and microbiology*. Cambridge University Press.

Becker, E. (2007). Microalgae as a source of protein. *Biotechnology advances, 25*(2), pp. 207–210. http://dx.doi.org/10.1016/j.biotechadv.2006.11.002

Bogut, I., Has-Schøn, E., Adamek, Z., Rajkovic, V., & Galovic, D. (2007). Chironomus plumosus larvae - a suitable nutrient for freshwater farmed fish. *Poljoprivreda Agriculture, 13*(1), pp. 159–162.

Chen, L., Wang, C., Wang, W., & Wei, J. (2013). Optimal conditions of different flocculation methods for harvesting Scenedesmus sp. cultivated in an open-pond system. *Bioressource technology, 133*, pp. 9–15.

Chisti, Y. (2007). Biodiesel from microalgae. *Biotechnology advances, 25*(3), pp. 294–306. http://dx.doi.org/10.1016/j.biotechadv.2007.02.001

Duong, V., Ahmed, F., Thomas-Hall, S., Quigley, S. N., & Schenk, P. (2015). High protein and high lipid producing microalgae from Northern Australia as potential feedstock for animal feed and biodiesel. *Frontiers in Bioengineering and biotechnology, 3*, p. 53. http://dx.doi.org/10.3389/fbioe.2015.00053

Gatrell, S., Lum, K., Kim, J., & Lei, X. (2014). Non-ruminant nutrition symposium: Potential of defatted microalgae from the biofuel industry as an ingredient to replace corn and soybean meal in swine and poultry diets. *Journal of animal science, 92*(4), pp. 1306–1314. http://dx.doi.org/10.2527/jas.2013-7250

Guedes, A., & Malcata, F. (2012). Nutritional value and uses of microalgae in aquaculture. In Z. Muchlisin (Ed.), *Aquaculture*. InTech.

Han, K., & McCormick, M. (2014). Evaluation of nutritive value and in-vitro rumen fermentation gas accumulation of de-oiled algal residues. *Journal of animal science and biotechnology, 5*(1), p. 31. http://dx.doi.org/10.1186/2049-1891-5-31

Hein, M., Foldager Pedersen, M., & Sand-Jensen, K. (1995). Size-dependent nitrogen uptake in micro and macroalgae. *Marine ecology progress series*(118), pp. 247–253. http://dx.doi.org/10.3354/meps118247

Janczyk, P., Wolf, C., & Souffrant, W. (2005). Evaluation of nutritional value and safety of the green microalgae Chlorella vulgaris treated with novel processing methods. *Archiva Zootechnica, 8*, pp. 132–147.

Leng, X., Hsu, K.-N., Austic, R., & Lei, X. (2014). Effect of dietary defatted diatom biomass on egg production and quality of laying hens. *Journal of animal science and biotechnology, 5*(3). http://dx.doi.org/10.1186/2049-1891-5-3

Lum, K., Kim, J., & Lei, X. (2012). Dual potential of microalgae as a sustainable biofuel feedstock and animal feed. *Journal of animal science and biotechnology, 4*(1), p. 53.

Moo-Young, M., & Gregory, K. (1986). *Microbial biomass proteins*. Springer Science and Business Media.

Smith, J., Gerrrard, C., Nelder, R., Clements, R., & Pearce, B. (2014). *100% organic feed for poultry - Results of feed trials in the UK*. ISOFAR, Johann Heinrich von Thünen-Institut.

Spolaore, P., Joannis-Cassan, C., Duran, E., & Isambert, A. (2006). Commercial applications of microalgae. *Journal of bioscience and bioengineering, 101*(2), pp. 87–96. http://dx.doi.org/10.1263/jbb.101.87

9. Nordic Sustainable Protein Production – Bioeconomy Potentials in Business and Society

By *Morten Gylling*, University of Copenhagen, Denmark

9.1 Introduction

This chapter will briefly describe the concept of bioeconomy and illustrate the relative economic importance of the bioeconomy in EU27 and the Nordic/Baltic region. The dependence on imported protein will be assessed together with the regional opportunities for production of soy protein substitutes. Finally, estimates of the economic potentials of green grassbased protein production will be presented based on a decentral and a central scenario.

9.2 Economic Interpretations of Bio-Economics

It is not straightforward to provide a precise definition of the term Bioeconomy in connection with the economic interpretation of the concept. The terms Bioeconomy (BE), Biobased economy (BBE) and Knowledge Based Bioeconomy (KBBE) are often used interchangeable, however, depending of the institutions/countries there are differences in the definitions. OECD and the US focus on the utilisation of life sciences and biotechnology while the EU using the terms BBE and KBBE considers the full chain from sustainable biobased raw material over bioprocessing to utilisation of the end-products.

The term Knowledge Based Bio Economy (KBBE) introduced in 2005/06 may actually be a better term in the sense that that it indicates that it takes knowledge/new knowledge and new/adapted technologies to transform/process biobased raw materials to new products and, thereby, expand the bioeconomy.

In this chapter, the definition of bioeconomy given by the Nordic Bioeconomy Initiative will be used (Norden, 2014).

The central components regarding bioeconomy are stated as:

- Sustainable production of biomass in order to increase the use of biomass products in a number of different sectors of society; intention to reduce climate impact and usage of fossil-based raw materials.
- An increased added value for biomass, while energy consumption is reduced, nutrients and energy are utilised as additional products. The aim is to optimise the value of ecosystem services and contribution to the economy.

This definition is very similar to the definition used by the EU and, therefore, enables us to compare the importance of the Nordic/Baltic bioeconomy and the EU Bioeconomy.

Using the abovementioned definition of BE/BBE, the following economic sectors are the basis for the Bioeconomy/Biobased economy:

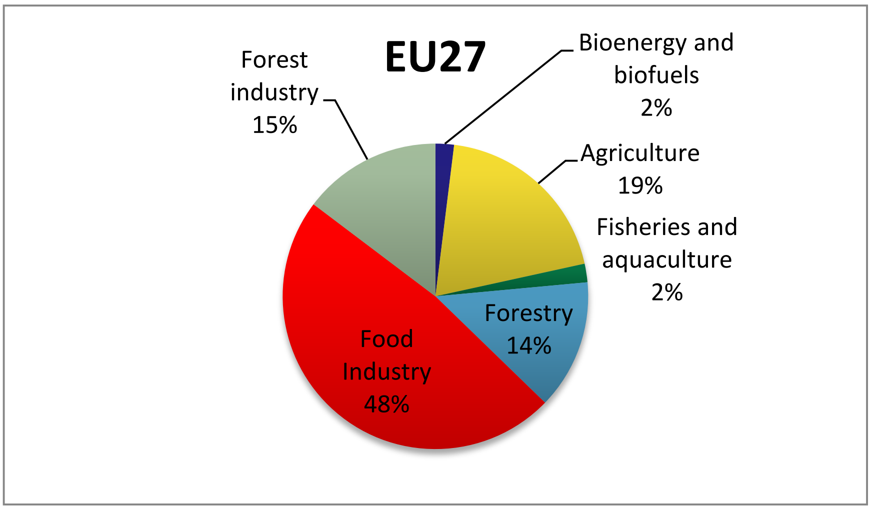
- Agriculture.
- Fisheries and aquaculture.
- Forestry.
- Food industry.
- Forest industry.
- Bioenergy and biofuels.

As can be seen from the list above, it is the traditional "biobased" sectors that constitute the bioeconomy, while the so-called emerging sectors like biobased chemicals and plastics, enzymes and pharma are not yet included; as being emerging, they still have a very small share of the total economy. The emerging sectors can be foreseen to become increasingly important both in order to "boost" the total bioeconomy but also to create possibilities to expand the "traditional" bioeconomy by using new biotechnologies in the production.

9.3 The EU-27 and the Nordic Bioeconomy

The economic size of the EU-27 bioeconomy (based on the six abovementioned economic sectors) was estimated to 1,782,027 MEUR in 2012 (Eurostat) and amounts to approx. 8% of the total EU-27 economy. The size of the individual economic sectors is shown in Figure 17. The food industry dominates the EU-27 bioeconomy with a share of close to 50%, followed by agriculture with a share of 20%. Forestry and forest industry together encompass close to 30% (Eurostat). The bioeconomy created 22,005,000 jobs corresponding to 8% of the total EU-27 employment (Eurostat).

Figure 17: The EU-27 Bioeconomy (2011/12)

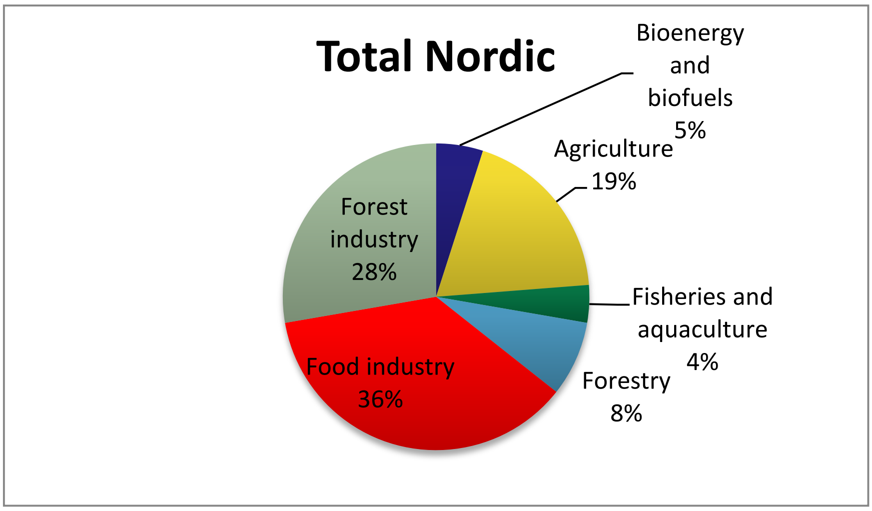


Source: Based on Eurostat.

The volume of the Nordic bioeconomy was estimated to 184,000 MEUR, which amounts to approx. 9% of the total Nordic economy (Norden 2014). The shares of the individual economic sectors are shown in Figure 18. The food industry is the most important sector with 37% followed by the forest industry with 28%. Agriculture and forestry accounts for 19% and 8% respectively (Norden 2014). Not surprisingly, forestry and the forest industry have a relative bigger share of the total bioeconomy in the Nordic region than in EU as a whole. The bioeconomy created 868,646 jobs corresponding to 7% of the employment.

An expansion of the bioeconomy is desirable because it can create new jobs and most of the jobs will be created in the rural and semiurban areas. Copenhagen Economics has in a recent study (CE 2015) on expanding the bioeconomy in Denmark found, that a very high (80%) proportion of the employment will go to the rural areas when we talk "traditional" biorefining.

Figure 18: The Nordic Bioeconomy (2011/11)



Source: Based on Norden, 2014.

9.4 Regional Proteins

The livestock production in EU as well as in the Nordic/Baltic region is heavily dependent on imported soy, and a production of "regional" proteins has been put forward as an opportunity to substitute imported soy and at the same time expanding the Nordic/Baltic Bioeconomy. The production of soy protein substitutes will also comply with some of the public concerns regarding the import of proteins from South America like deforestation, GMO and social issues in many soy-producing areas. At the same time, this will expand the bioeconomy "within the traditional bioeconomy" framework.

It should be emphasised that an expansion of the bioeconomy will depend on a sustainable and continuous reliable raw material supply at a given quality, investments in "biorefineries" and the technology and knowledge to process the raw material into high value products and a market for these products.

9.5 EU Balance of Protein-Rich Feeds

EU-27 produced around 20% of the world pig meat in 2011/12 (Compassion in world farming, 2015) and 15.4% of the world chicken meat in 2012 (The Poultry site, 2015). Both poultry and pig production demand high quality proteins in the feed ration and the production, therefore, creates a demand for high quality proteins.

A little better than 50% of the vegetable protein rich feed used in EU-27 is soy beans/meal of which close to 97% is imported, rapeseed and sunflower seed meals constitutes about 30% (Table 12).

Table 12: EU balance of protein-rich feeds in 2012

Material	EU production (000.tonnes)		EU consumption (000.tonnes)	
	Products	Proteins	Products	Proteins
Soy beans/meal	1,189	452	34,134	15,904
Rapeseed and sunflower seed/meals	27,481	5,213	19,721	6,329
Pulses	3,045	670	2,800	616
Dried forage	4,056	771	3,900	741
Miscellaneous plant sources	2,877	654	5,859	1260
Sub-total	38,648	7.76	66,414	24,850
Fish-meal	398	275	599	433
Total	39,046	8,035	67,013	25,283

Source: EIP Agri, 2014.

The EU dependency of imported soy can cause some concerns, but the volume of the import is not more than one quarter of the total world trade and the production in 2015/2016 is expected to exceed demand resulting in rising carryover stocks (IGC, 2014).

This dependency of imported protein is not new, historically postwar Europe has had a high level of protein deficit. Since the mid–seventies the deficit has been fluctuating between 80% and 68% and only in few periods been less than 70%. Part of the reason for the fluctuation can be found in changes in the EU production of vegetable proteins and a rise in animal production within the last decenium. Since the start of the EU Common Agricultural Policy (CAP) in 1963, the production of vegetable protein has been supported mainly by two different schemes, one addressing processing and products and one addressing individual crops.

9.6 Dehydrated/Dried Fodder Scheme

The scheme started in 1974 with the establishment of a common market organisation (CMO) for dried fodder. At the start the support was paid to the drying industry, which in 1978 was followed by a price support. The production expanded rapidly during the 80s and in order to control costs, a production control was introduced in 1995. A system of maximum guarantied quantity (MGQ) was adopted and each country was given a maximum quota. The annual EU maximum guarantied quantity was 4,412,400 tons of dehydrated fodder and 443,500 tons of sundried fodder. The production has since the introduction stayed close to the MGQ (COM, 2008). In the period up to 2012, the scheme was changed from processing aid to be integrated into the single payment scheme. In 2012, the EU27 production was 4,056,000 tons equal to approx 741,000 tons of protein (Eurostat).

The Nordic/Baltic region had in 2004 a MGQ of 362,188 tons (DK 334,000 t.; FI 3,000 t.; LT 650 t.; PL 13,538 t.; SE 11,000 t.), in total equal to 163,815 tons protein. After 2012 there is hardly any production in the Nordic/Baltic region (Eurostat).

9.7 Protein Crops and Oilseeds

The EU support to oilseeds and protein crops has since the introduction of the Common Agricultural Policy been provided through a complex system of market measures and product/crop specific subsidies. The system has for budgetary reasons been gradually simplified during the 90s. All subsidies are now integrated into the Single Payment Scheme.

In 1961, nearly 6 million ha were cropped with various species of grain legumes. Pea and soy bean (the majority being used as animal feed) became the most widely grown protein crops following the introduction of policy support for protein feed crops in the 1970s. Later there has been a growth in the production of oilseeds, and a decline in forage and grain legumes production. Grain legumes (protein crops) declined from 5,800,000 ha in 1961 (4.7% of the arable area) to 1,900,000 ha in 2011 (1.8% of the arable area). In Northern Europe, Poland and Lithuania still have a sizeable production of grain legumes.

The major oilseed crops in EU are sunflower and rapeseed of which sunflower is not relevant for the Nordic/Baltic region. The EU 27-production of sunflower meal was 4,127,000 tons in 2014. The rapeseed meal production has raised from 6,000,000 tons to 14,203,000 tons in

2014 (Eurostat). The more than doubling in production in a 10-year period is caused by the expanding biodiesel production.

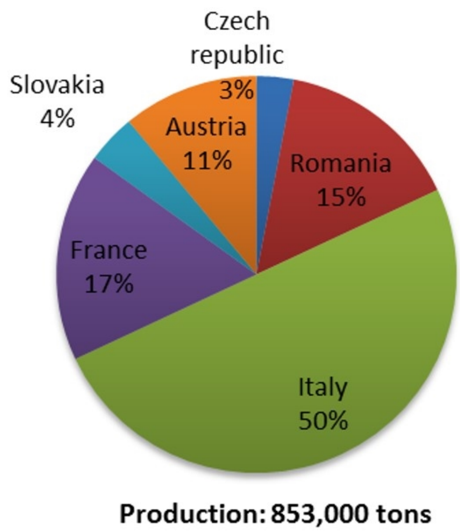
The production of oil rapeseed in the Nordic/Baltic region was 4,803,488 tons in 2013 (Eurostat), close to 50% of the EU 27 production. Poland is the by far largest producer with a little better than half of the production followed by Denmark, Lithuania and Sweden.

As stated above a little better than 30% of the vegetable protein rich feed used in EU27 is rapeseed and sunflower seed meals. However, as described in the preceeding chapters both rapeseed meal and sunflower seed meal have nutritional characteristics that limit their uses in feed mixes and therefore they are only partly substitutes for soymeal.

9.8 Production and Import of Soy to EU-27

In the EU-27 approximately 400,000 hectares of soy was grown in 2012 (EIP Agri, 2014), which only represents around 3% of what Europe needs to produce for animal feed (900,000 tons. As can be seen from Figure 19, 50% of the soybeans are grown in Italy, while France and Romania grows 17% and 15% respectively. Before joining the EU, Romania had a larger and expanding production of soybeans including GM soybeans producing 345,000 tons in year 2006 but due to the EU ban on GMOs the production today is much lower and only of conventional varieties.

Figure 19: EU-27 soybean production – 2012

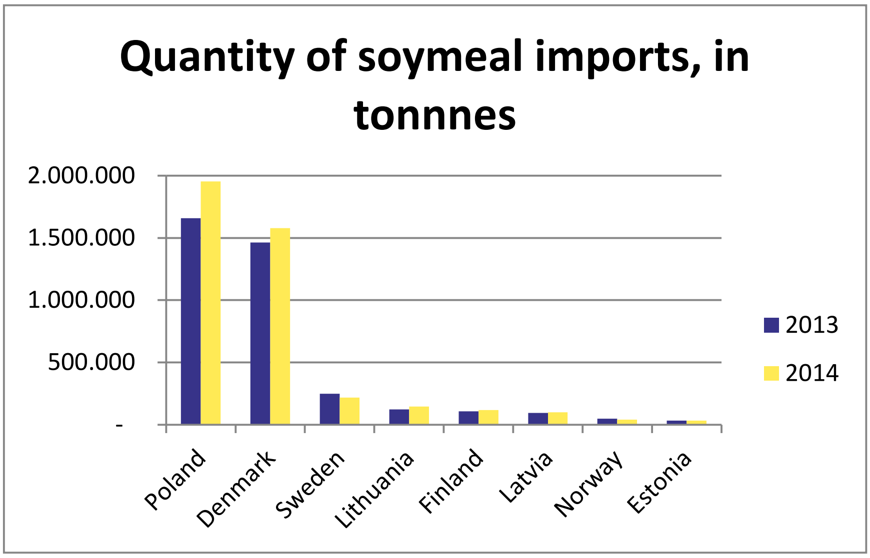


Source: EIP Agri, 2014.

9.9 Import of Soymeal to the Nordic and Baltic Region

The Nordic and Baltic countries are in the same situation as the EU-27 and there is hardly any commercial production of high-grade vegetable proteins suitable for monogastrics. The Nordic and Baltic countries count for a little better than 22% of the pigs in EU (calculated as LSU) and 14% of the poultry (calculated as LSU) (Eurostat), which strongly indicates a high demand for high-grade protein. As can be seen from Figure 20, the Nordic and the Baltic Region imported 3,700,000 tons of soymeal in 2013 and 4,200,000 tons in 2014, which equals 12–13% of the EU-27 import.

Figure 20: Import of soymeal to Scandinavia and the Baltic region (2013/2014)



Source: Eurostat.

The import had a value of EUR 1,755,000,000. As it can be seen Poland and Denmark are the two big importers with more than 80% of the total imported volume and value.

9.10 Production of Regional Alternatives to Soy

In the sections above it has been described that there is a high volume and high value market for alternative regional proteins. Furthermore, in the previous chapters a number of "Nordic alternatives" to soy are suggested:

- Algae.
- Mussels.
- Insects.
- By-products of the production of vegetable oils (mainly rapeseed).
- Single cell protein.
- Grain legumes and peas.
- Biorefined "green" proteins from grass.

To illustrate the "bioeconomic" potentials for production of regional proteins to substitute soymeal, grass based green proteins has been chosen as an example mainly because grass has a high and stable yield potential in Scandinavia/Baltics and it is an environmentally efficient crop.

9.11 Economic Potential for Producing Green Grass Based Proteins

In this section the estimated economic potentials of a central and a decentral grass based Biorefinery are shown. The calculations are mainly based on a feasibility study presented by Ambye-Jensen (2015) as far as the technical data and estimated product prices are concerned while the raw material cost (production, harvest and transport costs of fresh grass) are based on Termansen and Gylling (2015).

The economic potentials are shown for two scenarios, a decentral scenario with an annual capacity of 20,000 tons DM and a central scenario with an annual capacity of 150,000 tons DM. The mass balances are based on a "well fertilised" grass crop.

Further technical details are shown below:

9.11.1 Decentral Scenario

- 20,000 t DM/yr equal to 10 tonnes DM/hr.
- In combination with a biogas plant.
- No drying of protein concentrate.
- Blended in a wet feeding system at approx. 40% DM.
- Placed close to ruminant and monogastric livestock.
- Investment: EUR 2,000,000.

9.11.2 Central Scenario

- 150,000 t DM/yr equal to 50 tonnes DM/hr.
- In combination with a biogas plant.
- Including upgrading of protein concentrate.
- Drying and pelletizing of protein conc.
- Investment: EUR 70,000,000.

9.11.3 Estimated Costs and Sales Prices

Table 13: Estimated costs and sales prices

Cost Estimate Grass (10 tonnes dm/ha in Rotation	99,3 EUR/tonnes DM (growing cost)
Sales Price Protein Concentrate	400 (EUR/tonnes DM)
Sales Price Upgraded Protein Concentrate	800 (EUR/tonnes DM)
Sales Price Grass Fibre	135 (EUR/tonnes DM)

Source: Ambye-Jensen (2015).

9.11.4 Estimated Economic Potentials

Table 14: Economic Potentials of Grass Biorefinery

	Central plant EUR	Decentral plant EUR
Protein concentrate		1,800,000
Upgraded protein concentrate	22,952,000	
Grass fibre	13,122,000	1,877,000
Income,	*36,074,000*	*3,677,000*
Cultivation/harvest	14,076,702	1,876,894
Transport	3,750,000	
Cost I,	*17,826,702*	*1,876,894*
Gross margin I, EUR	*18,247,298*	*1,800,106*
Energy,	6,000,000	240,000
Salaries,	750,000	100,000
Maintenance,	2,800,000	100,000
Cost II,	*9,550,000*	*440,000*
Gross margin II, EUR	*8,697,298*	*1,360,106*
Depreciation and interests, EUR per year	*5,616,981*	*192,685*
Total cost,	*32,993,683*	*2,509,578*
Refining costs per ton DM	*126*	*32*
Profit,	3,080,317	1,167,422
IRR	10,84%	67,98%

Source: Ambye-Jensen (2015).

The estimated economic results are positive for both scenarios, with positive Internal Rate of Return (IRR). However, it takes some caution to compare the two investments as the scales are very different and basically the two scenarios are producing different end-use products. The results show that it is possible to achieve positive economic results based on fairly simple setups with only two products.

It should, however, be emphasised that the abovementioned results are based on pilot scale results and project results from the BIOVALUE project (www.BIOVALUE.dk). Therefore, additional economic assessments must be performed before final investment decisions can be made.

9.12 Summary/Conclusion/Potential for Value Added

- The Nordic Bioeconomy is based on a strong resource base of forestry and agriculture amounts to approx. 9% of the total Nordic economy and creates about 8% of the employment.
- Despite of a number of EU support schemes for vegetable protein crops/products the EU-27 protein deficit has never been less than 70%.
- The Nordic/Baltic region has a fairly big share of the EU production of pig meat and chicken meat, which creates a high demand for high quality feed protein.
- The Nordic/Baltic market for soy protein substitutes is in the range of 4,000,000 tonnes with an estimated value of EUR 1,800 M.
- It is estimated that a Nordic/Baltic production of green protein substitutes based on green grass biorefining can be economic viable both in small and large scale.
- A 10% substitution of the Nordic/Baltic import of soy protein will constitute a potential market of 400,000 tonnes protein at a value of approx. EUR 180 Mill.
- Grass in the Nordic/Baltic region have a medium to high production potential and a production of grass based "green protein" substitutes in the Nordic/Baltic region will be based on well known logistics systems.
- A production of grass based green protein has the potential to create rural and semi urban jobs.

9.13 Recommendations

A demonstration programme should be initiated to demonstrate available pilot scale results in a full value chain setting for grass based green protein biorefineries. An initiative should be taken to map the various activities within "green grass based protein" and facilitate knowledge sharing and cooperation.

9.14 References

Ambye-Jensen, M. & Adamsen, A.P. (2015): *Green Biorefinery Feed Protein – feasibility study on scale of implementation.* Presented at the International Conference on Renewable Resources & Biorefineries (*RRB-11*) in *York, June 2015.*

COM (2008). *570 final*. European Commission. Report from the Commission to the council.

Compassion in world farming (2015). www.ciwf.org.uk : Statistics *Pigs.*

Copenhagen Economics (2015): *Geografiske beskæftigelsespotentialer i bioøkonomi*. Fagligt Fællesforbund, 3F, 16.juni, 2015. (in Danish).

EIP-AGRI (2014). *EIP- AGRI Focus Group Protein Crops – final report*. (14 April 2014).

Eurostat. Retrieved from ec.europa.eu/eurostat

Gylling, M., Jørgensen, U., Bentsen, N.S., Toft, I., Dalsgaard, T., Felby, C., & Kvist, V. (2012). *+10 mio. tons planen: muligheder for en øget dansk production af bæredygtig biomasse til bioraffinaderier.* Fødevareøkonomisk Institut, Københavns Universitet, 2012.

International Grains Council (2014). *Five-year global supply and demand projections.*

Norden (2014). *Creating value from bioresources*. Nordic innovation report 2014:01.

Reichert. T. (2006). *A closer look at EU agricultural subsidies*. Developing Modification Criteria. Germanwatch.

Termansen & Gylling (2015). *Notat om grøn biomasse til det Nationale Bioøkonomi-panel - Nationalt Center for Miljø og Energi*.

The Poultry site (2015). *Global poultry trends 2014.* Retrieved from www.thepoultrysite.com

10. Life Cycle Assessment of Alternative Protein Sources: Constraints and Potentials

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10.1 Introduction

Our food consumption is responsible for approximately one third of our total environmental impact, and feed production for livestock is a major part of this. The Northern-European livestock sector depends heavily on imported soybeans as a major protein source. However, one of the concerns related to the import of soybeans and soybean meal to the livestock sector in Europe, is the environmental issues associated with the import and soybean production in South America. Another concern is the massive dependency on import of protein crops that makes the EU livestock sector vulnerable to price volatility and trade distortion (De Boer *et al.,* 2014), since there is an increasing global demand for soybeans. The main environmental problems that have been reported in relation to soybean production in South America is deforestation (European Commission, DG Environment, 2013), vast areas of monocultures and a pesticide use that have negative health impacts (Hermansen *et al.*, 2014; Bosselman & Gylling, 2014; WWF, 2014). Thus, alternative protein sources produced in EU are needed. At the same time, there is an increasing pressure on land for food, feed and biofuels, so the alternative protein production in EU should ideally use a minimum of land and should affect the environment as little as possible. Several alternative protein sources have been suggested such as protein from marine biomass (mussels, algae, waste from fisheries), protein produced from agricultural biomass such as grain legumes or grass/clover in biorefineries along with bioenergy, or protein from insect larvae based on e.g. organic waste or sidestreams from households, agriculture, food industry etc., or finally production of single cell proteins grown on e.g. agricultural wastes, by-products from oil refineries or natural gas. The main question is however, is it environmentally better to replace the soymeal with those alternative protein sources – and which one of them is most environmentally friendly? And how to assess the alternatives?

Life cycle assessment (LCA) is a widely used tool to assess environmental sustainability and the potential environmental impacts of a given product to support decision making in the production and consumption (ISO, 2006). Today, life cycle assessments are widely used and are one of the preferred methods for calculations of environmental impacts. LCA is integrated in EU's policy instruments and in private companies' environmental information systems (de Souza *et al.,* 2014). In agriculture, the LCA approach is very helpful because it gives an overview of the environmental impact and resource consumption in every step of the production chain from the production to their transformation into e.g. feed protein. Thus, life cycle assessment can be used to assess and compare the environmental impacts and resource uses associated with the alternative protein sources.

However, very few LCA studies have so far been conducted on the abovementioned alternative protein sources. Thus, at the same time there is also a need for methodological development within life cycle assessments related to the new alternative production chains.

The aim of the present chapter is to give a short introduction to the LCA methodology, followed by a review of what have been done so far of LCA's on alternative protein sources. Finally, constraints and potentials based on the few LCA's of alternative protein sources will be discussed.

10.2 The Life Cycle Assessment Methodology

As previously mentioned, the production and extraction of bio-protein from alternative sources should take into consideration the environmental impacts and life cycle assessment (LCA) is one of the most comprehensive methods for assessing the environmental burden of a product. Therefore, in the following section, we will briefly introduce and describe the main phases of a LCA assessment.

ISO (International Standardization Organization) developed ISO 14044:2006, which sets up the guidelines for LCA methodology. It consists of four main phases: definition of goal and scope; inventory analysis; evaluation of the environmental impacts and interpretation of the results.

10.2.1 Goal And Scope

The first phase of a LCA implies setting up the frame for the analysis, which includes defining an aim, a functional unit, the system boundaries, cut-off-criteria and impact categories (ISO 14044:2006).

The goal of an LCA reflects the framework of the study as an LCA can be carried out with different purposes. Therefore, there can be documentation studies (e.g. for green market or for a client) or product development or improvement studies. At the same time, the focus can be on a single product ("single product LCA") or on more products ("comparative LCA") (Thrane & Schmidt, 2004).

The functional unit represents the object of the study and it is also called the "reference unit". It is strongly connected with the goal of the study and in consequence it may reflect a quantity (e.g. amount, volume, size), a duration period or qualitative characteristics (depending on the goal of study) (Thrane & Schmidt, 2004).

System boundaries delimit the processes that are included in the analysis. This delimitation is made in relation to the goal and scope as well. The boundaries used for the analysis of a system depend very much on the type of approach that is going to be used: attributional (ALCA) or consequential (CLCA) LCA. According to Thrane & Schmidt (2004), the consequential LCA includes the processes that are affected by the production of the analysed product, while the attributional LCA takes into consideration only the processes that are part of the supply chain.

Cut-off-criteria contributes as well to the delimitation of the system boundaries by specifying the level of detail for data collection (Thrane & Schmidt, 2004). For instance, most of the agricultural systems put a pressure on the land use and, therefore, on the land use change (LUC). However, in some studies, LUC represents one of the cut-off-criteria.

The impact categories have to reflect the environmental issues associated with a system without disregarding the scope of the study, according to ISO 14044:2006. The impact categories may refer to global issues (e.g. global warming potential), regional issues (e.g. acidification, eutrophication) or to local issues (e.g. human toxicity) (Thrane & Schmidt, 2004).

10.2.2 Inventory Analysis (Life Cycle Inventory, LCI)

The main aim of this phase is to collect the data and estimate the emissions. This phase implies the three aspects: data collection (quantitative and/or qualitative data), calculations and handling the co-products. The last operation refers to the division of emissions between the different co-products and it is a challenge especially when the systems are complex and multifunctional (Thrane & Schmidt, 2004).

In order to standardise this operation, ISO developed a stepwise procedure, which regards firstly the division of the process unit into sub-processes (with different inputs and output). When that is not possible, system expansion should represent the next option. The last suggestion includes the allocation between the co-products based on physical relationship, or if not on other relationships (e.g. economical relationships) (ISO 14044:2006).

Potential land use changes should also be considered, when estimating the emissions that contribute to the environmental impact categories, and included in the global warming impact category. According to the widely accepted carbon footprint guideline PAS2050 (BSI, 2011), emissions from direct land use changes (dLUC) should be included in the LCA calculations. Direct land use changes occur if e.g. forestland is cleared to produce agricultural crops. According the PAS2050, the emissions from direct land use change should be included in the agricultural LCA, if the land has been cleared for agriculture less than 20 years ago. Another approach to the land use change issue in LCA's is using the argument that all agricultural activity has indirect land use change (iLUC) effects (i.e. that growing more of any crop will increase the land use pressure elsewhere, due to the global market). According to this approach, the land use change emissions should be equal for all crops per ha and not be dependent on the location of the agricultural production (Audsley *et al.*, 2009; Schmidt *et al.*, 2015).

10.2.3 Evaluation of the Environmental Impacts (Life Cycle Impact Assessment, LCIA)

This phase of the analysis refers to obtaining appropriate results through classification and characterisation. During classification, the calculated emissions are distributed between the analysed impact categories. As different type of emissions can contribute to the same impact category (e.g. CO_2, N_2O and CH_4 emissions contribute to global warming potential) it is necessary to evaluate them by using the same unit. This operation is known as characterisation (Thrane & Schmidt, 2004).

The interpretation of the results is the last phase of the study and it implies the identification of the "hotspots" and the presentation of the most important results. This section might include as well a sensitivity and/or uncertainty analysis (Thrane & Schmidt, 2004).

10.3 Overview of LCA Studies on Alternative Protein Sources

The following section will present a review of the few LCA studies conducted on alternative sources of protein. The literature review was focused on the methodology used, such as functional unit, system boundaries, impact categories and land use change. The LCA studies were classified into four main categories: marine biomass; agricultural biomass; insects and single-cell protein. The four categories and the related LCA studies are presented in Table 15.

Table 15: LCA studies conducted in the field of alternative protein sources

Type of biomass	Impact categories	System boundaries	LUC	References
Marine Biomass				
Defatted algae	- Global warming potential. - Land occupation. - Fossil depletion.	A cradle to farm gate approach.	+/-	Sills *et al.*, 2013 & De Boer *et al.*, 2014.
Mussels	- Global warming potential. - Eutrophication potential. - Acidification potential.	A cradle to processing approach.	-	Spångberg *et al.*, 2013.
	- Global warming potential. - Eutrophication potential. - Acidification potential. - Biotic depletion etc.	A cradle to consumption approach.	-	Iribarren *et al.*, 2010.
Agricultural Biomass				
Soybean and other grain legumes	- Global warming potential etc.	A cradle to farm gate approach.	+/-	Dalgaard *et al.*, 2007. De Boer *et al.*, 2014. Leionen *et al.*, 2013. Knudsen *et al.*, 2014.
Oil seed crops (high-protein sunflower seed meal and rapeseed cake)	- Global warming potential etc.			De Boer *et al.*, 2014. Mogensen *et al.*, 2014.
Insects				
Mealworms	- Global warming potential. - Fossil energy use. - Land use.	A cradle to farm gate approach (until the worms leave the farm gate).	-	Oonincx and De Boer, 2012.
	- Global warming potential. - Land occupation. - Fossil depletion.	A cradle to farm gate approach (until the worms leave the farm gate).	+/-	De Boer *et al.*, 2014.
Housefly larvae	- Global warming potential. - Energy use. - Land use.	Egg production, larvae production, substrate/feed production for larvae, processing of larvae.	-	Van Zanten *et al.*, 2014.
Single-Cell Protein				
Bacterial single-cell protein	- Global warming potential. - Land occupation. - Fossil depletion.	The production process.	+/-	De Boer *et al.*, 2014.

10.4 Marine Biomass

The marine biomass category represents the sources from the marine environment that could serve as a source of bio-protein. Most of the LCA's conducted on marine biomass has been on fish (Parker, 2012) and fishmeal (Thrane, 2006; LCA.food.dk). Other types of sources, such as algae and mussels have only recently come into focus and, therefore, only little information can be found. The few LCA studies found on defatted algae focuses primarily on biofuel and for mussels the focus is primarily on food consumption or the use of mussels as fertiliser. These studies will be presented with more details below.

10.4.1 Defatted Algae

Defatted algae (microalgae, macro algae, duckweed) are by-products from the biofuel industry that have a high content of protein. This aspect led to the investigation of their potential to replace soybean meal or maize in animal diets. Thus, Gatrell *et al.* (2014) showed that swine and poultry could tolerate the incorporation of this type of biomass into diets.

De Boer *et al.* (2014) performed an LCA in order to investigate the differences between the use of soybean meal and other sources of alternative protein in pig diets. Defatted algae represented one of the tested scenarios from this study. The estimation of the emissions (CO_2 eq.) was carried out with the calculation tool; FeedPrint. Both attributional and consequential LCA approaches were used.

The LCA was based on the study of Sills *et al.* (2013), where algae were used for biofuel production. The advantage of using this method is that all the upstream emissions are credited to biofuel production, while the oil extraction process is the only source of emissions that is attributed to defatted algae. There are two possibilities for extraction: wet and dry extraction and according to Sills *et al.* (2013) the first one has the lowest carbon footprint. 1 kg of dried defatted algae results from the removal of 4.7 kg water from 5.7 kg of wet biomass. However, De Boer argues that the energy use for thermal drying can be reduced if it is preceded by different procedures, such as membrane filtration, mechanical vapour recompression or thermal vapour recompression. The allocation between the oil content and the value of protein is based on economic values.

According to De Boer *et al.* (2014) the production of defatted algae does not put a pressure on LUC (their contribution is equal to 0).

10.4.2 Mussels

As mentioned previously, mussel farming has just recently been analysed from a life cycle perspective and it was difficult to find studies that focus on the extraction of protein from mussels. However, the cultivation of mussels was part of three LCA studies and we included the relevant methodology aspects from those studies in the following section.

Spångberg *et al.* (2013) described this process in relation to mussels' use as fertilisers. Three impact categories were studied in relation to the production and distribution of 100 kg of plant available nitrogen (functional unit): eutrophication potential (PO_4^{3-} eq.), acidification potential (SO_2 eq.) and global warming potential (CO_2 eq.). All the processes for obtaining of fertilisers were included: the production of cultivation materials and fertilisers, spreading the fertilisers on the fields and disposal of material. The cultivation of mussels was assumed to be done in net in June until the harvest in October–December. In the study, the avoided activities were accounted for through system expansion (Spångberg *et al.*, 2013). The eutrophication potential had negative values due to the fact that mussels take up nitrogen and phosphorus while they grow (Spångberg *et al*., 2013).

The cultivation of mussels was also assessed by Iribarren *et al*. (2010a). The study was focusing on the human consumption of mussels as fresh products or canned. Many impact categories were included: biotic depletion, global warming, ecotoxicity, human toxicity, acidification, ozone layer depletion, photochemical oxidant formation and eutrophication.

A more complete view on the LCA methodology related to the culture of mussels is given in the study of Iribarren *et al.* (2010b). The system boundaries include the following activities: seed collection; pre-fattening the seed; rope thinning; harvesting, selection and previous packaging; construction, operation and maintenance of the raft; construction, operation and maintenance of the auxiliary cultivation boats. Data collection was done through in situ questionnaires that were filled in by the skippers of the different boats in charge of 80 rafts, which corresponds to a total production of 7,180 tons of mussels.

10.5 Agricultural Biomass

The most commonly used protein source from agricultural biomass is soybean meal from South America. Several LCA studies have estimated the carbon footprint of soybean meal such as De Boer *et al.* (2014), Dalgaard *et al.* (2007), Leinonen *et al.* (2013), Knudsen *et al.* (2014), Concito *et al.* (2014) and Bosselman & Gylling (2014). The carbon footprint values in those studies range from approximately 0.60 to 0.95 kg CO_2 eq. kg^{1} soymeal, excluding land use changes and from 0.78 (De Boer *et al.*, 2014), 2.25 (Leinonen *et al.*, 2013) and 2.0–3.8 (Concito, 2014; Bosselman & Gylling, 2014) kg CO_2 eq. kg^{1} soymeal, including land use changes have been reported. Since the main focus is finding alternatives to the use of soybean meal the carbon footprint of soybean meal can be used as a reference in the comparison of alternative protein sources. The variation in the carbon footprint values incl. land use change depends on the method used to estimate land use change effects. For the carbon footprint values of 2–3.8 kg CO_2 eq. kg^{1} soymeal (Leinonen *et al.*, 2014; Concito, 2014), indirect land use change effect have been used.

10.5.1 Grain Legumes

Other grain legumes that can be produced in Europe such as field pea, faba beans and lupins are relevant alternatives to soymeal in livestock diets, which has been investigated in Leinonen *et al.* (2013) and Baumgartner *et al.* (2008). The carbon footprint of locally produced faba bean and field peas are approximately 0.1–0.5 kg CO_2 eq. kg^{1} faba bean or pea or 0.4–1.8 kg CO_2 eq. kg^{1} protein in faba bean or pea (Knudsen *et al.,* 2014; Leinonen *et al.*, 2014). As a comparison, imported soybean meal has a carbon footprint of approximately 2.0 kg CO_2 eq. kg^{1} protein in soymeal (excl. land use change) (based on Leinonen *et al.*, 2014) or 4.6–7.8 kg CO_2 eq. kg^{1} protein in soymeal (incl. indirect land use change) (based on Leinonen *et al.*, 2014 and Concito *et al.*, 2014).

10.5.2 Oilseed Crops

Alternative agricultural protein sources are cakes or meals from oilseed crops, such a sunflower meal or rapeseed cake (Leinonen *et al.*, 2013; Mogensen *et al.*, 2014). Mogensen *et al.* (2014) estimated the carbon footprint of rapeseed cake to approx. 0.5 kg CO_2 eq. kg^{1} DM.

De Boer *et al.* (2014) included high-protein sunflower seed meal in a comparison study. High-protein sunflower seed meal is not a product that can be found on the market. However, De Boer *et al.* (2014) assumed that the soybean meal with high-protein sunflower seed meal could replace the soybean meal in animal diets. De Boer *et al.* (2014) study was based on the assumption that fibre can be removed from sunflower seed meal and by that the crude protein can increase to 46% as compared to 38% (the level in the available sunflower seed meal). The LCA study included the crop production, the processing of crop and animal products, fibre removal, compound feed production to utilisation by the animal and the transport and storage between all steps of the production chain (FAO, 2014). The carbon footprint was approx. 0.6 kg CO_2 eq. kg^{1} high-protein sunflower seed meal (De Boer *et al*., 2014).

10.5.3 Perennial Grass and Legume Crops

Protein in perennial grasses, grass-clover or alfalfa is mainly directly digestible for ruminants and is thus not an obvious alternative protein source for pigs and poultry. However, if the protein is extracted in a biorefinery it might serve as a relevant alternative protein source for pigs and poultry (Termansen *et al.,* 2015). So far, only very few LCA studies have dealt with biorefinery systems (Cherubini *et al.*, 2010; Ahlgren *et al.*, 2015).

10.5.4 Distiller's Dried Grains with Solubles (DDGS)

DDGS is a co-product of the bio-ethanol production with a protein content of approx. 25%. DDGS can be produced from different grains, e.g. maize and wheat during the bioethanol production. DDGS are increasingly used in practice to replace soybean meal in livestock diets. De Boer *et al.* (2014) has estimated the carbon footprint of maize-DDGS to be approximately 0.6 kg CO_2 eq. kg^{1}. The carbon footprint value is caused by the drying of the product, and no upstream processes are included due to the low economic value of the wet product before it is dried.

10.6 Insect's protein

Insects represent as well a source of protein that could be used in animal feeding. One of the advantages of implementing that into practice would be that the production technology could utilise the waste (e.g. organic household waste, agro-industrial waste, etc.). Therefore, more and more studies aim at investigating the environmental benefits of this alternative protein source. Two LCA studies concerning mealworms and one LCA study concerning housefly larvae are described in the following section.

10.6.1 Mealworms

There are only a few studies that has investigated the role of mealworms in animal feeding due to their high protein content (Van Krimpen *et al*., 2013; Veldkamp *et al*., 2012) and only one LCA study (De Boer *et al*., 2014), which is based on a LCA assessment of mealworms used in human consumption (Oonincx and De Boer (2012)). Thus, the two LCA studies will be described in the following.

Oonincx and De Boer (2012) assessed the environmental impact of the production of two tenebrionid species: the mealworm (Tenebrio molitor) and the super worm (Zophobas morio). Two functional units were considered: kg fresh product and kg edible protein. The edible protein was assumed to be the same as the crude protein content, which represented 53% (T. molitor), respectively 45% (Z. mario) of the dry matter of a fresh product. Three impact categories (GWP, fossil energy use (EU) and land use (LU)) were quantified and the production system included all the emissions from cradle to farm gate. That refers to various sub-processes such as: production of feed ingredients (carrots and carrot side product, mixed grains) and production of mealworms (egg trays, gas, electricity, water, manure). The allocation of the environmental burden of the feed products was done based on their economic value and the emissions related to mealworms production were attributed in totality to the obtained products. The results showed a lower impact for mealworms as compared to milk, pork, chicken and beef production for two impact categories: GWP and LU. The EU of mealworms was higher than the one of milk production and similar to the one of pork, chicken and beef.

The previous study was included in De Boer *et al.* (2014), which assessed the environmental burden of different European produced protein sources that could replace soybean meal of South-American origins. There were considered various scenarios for pig feeding, which were evaluated in relation to a reference scenario (where soybean meal originating from South-America is used). For each of them, carbon footprint, land occupation and fossil depletion was estimated.

The scenario according to which the soybean meal can be replaced with protein from mealworms was based on the assumption that dried mealworms could substitute soybean meal on at least 1:1 basis. The crude protein content of fresh mealworms is 49% in dry matter, which is comparable to the one of soybean meal. In this case, the carbon footprint was significantly higher than for soybean meal, as the feed included carrots and mixed grains (although a more appropriate solution will be the production on organic waste or by-products) and the energy use was very high. Furthermore, obtaining 1 kg of dried mealworms implied the use of 2.15 kg fresh mealworms. The study did not include the fact that the price of mealworms is 50 times higher than that of soybean meal (De Boer *et al.*, 2014).

10.6.2 Housefly Larvae

Insects, such as housefly larvae can be transformed into a protein source for livestock feed due to various reasons: they have high protein content and a very efficient feed conversion and they can utilise organic waste streams (e.g. manure, household waste, food products' waste) (Van Zanten *et al*., 2014). In that context, Van Zanten *et al.* (2014) investigated the potential of this method of producing protein in a LCA study, which is presented below.

The study of Van Zanten *et al.*, (2014) was conducted on housefly larvae that were grown on 195 tonnes of food waste, 65 tonnes laying hen manure and 1 ton premix. The functional unit was represented by 1 kg dry matter of larvae meal. The system boundaries included four sub-processes, as follows: egg production, larvae production, substrate/feed production for larvae and processing of larvae in order to produce larvae meal. This system implied the production of 1 kg larvae per 4 kg substrate, which equals to 65 tons of live larvae per day and 20 tons of larvae meal with 88% dry matter and 159 tons larvae manure. The impact categories that were analysed were global warming potential, energy use and land use. It was argued that manure, which is produced in the process is not a waste and that it for instance can be used as substitute for fertiliser, but that process was not included in the analysis. The carbon footprint of larvae meal was 0.8 kg CO_2 eq. kg^1 (lower than that of fishmeal. The production process for that implies as well the use of 9,329 MJ energy (similar to fishmeal and higher than that of soybean meal) and 32 m^2 land use (similar to fishmeal and lower than that of soybean meal).

10.7 Single Cell Proteins

The single-cell proteins are sources of protein that can be extracted from algae, yeasts, fungi or bacteria. They can be grown on agricultural wastes, by-products from oil refineries or natural gas (De Boer *et al.*, 2014).

An LCA assessment was performed of bacterial single-cell proteins that were grown on natural gas with the aim of replacing soybean meal in animal diets. The study was conducted by De Boer *et al.* (2014). The estimation of the emissions (GWP) was carried out with the FeedPrint by incorporating data collected from literature. The input data were those from the study of Huizing (2005). The system process was described by taking as a reference the production of single-cell proteins in UniBio (Denmark) and it implies various sub-processes: a continuous fermentation with 2–3% dry matter in biomass, centrifugation before harvest, heating at 1,400C for sterilisation, cooling for making the proteins more accessible and drying of the biomass. The carbon footprint was estimated to be approx. 5 kg CO_2 eq. per kg dried product (88% dry matter). The calculations did not include the emissions due to transportation to feed mill and those associated with some processing (e.g. grinding). LUC was included and the results showed almost no pressure, since the land requirements include only the production facilities.

10.8 Constraints and Potentials

Overall, all the sources that were included in the previous sections represent potential alternative protein sources for animal feed. However, there are some constraints related to their implementation. High protein sunflower meal is the only alternative that has a carbon footprint similar to the one of soybean meal, while insects, defatted algae and single-cell proteins have higher carbon footprints than the reference (soybean meal). Nevertheless, it is clear that very few LCA studies have been conducted so far on alternative protein sources. De Boer *et al.* (2014) has made a comparison of carbon footprint of a number of alternative protein sources based on the few studies made so far suggesting that the alternative protein sources have carbon footprints that are comparable or higher than for imported soybean meal. However, De Boer *et al.* (2014) has used a very low carbon footprint value of soybeans (0.7 kg CO_2 eq. kg^1 soymeal) compared to other reported carbon footprint values for soymeal (2–3.8 kg CO_2 eq. kg^1 soymeal), where impacts of land use change have been included. Some of the hotspots in the carbon footprint values for the alternative protein sources are the high-energy use during the drying stages of the production. There are also some practical and economic issues with regard to their implementation (e.g. sanitary issues and high associated production costs for mealworms and bacterial single-cell proteins). On the other hand, there are many benefits in using alternative sources of protein e.g. with regard to the land use change pressure. The extraction of protein from defatted algae or from bacterial single-cell protein seems to have no contribution to LUC.

However, no conclusions should be made yet and there is clearly a need for more LCA studies in order to make a fair comparison between alternative protein sources, both to improve and develop the LCA methodology within this area and to optimise the actual production chains of the proteins.

With regard to the optimisation of the production chains of alternative proteins, the knowledge so far is scarce due to the few LCA studies conducted. However, the studies have indicated a few issues. Looking at aquatic proteins, or other wet processes, the drying process is very energy consuming and a hotspot in the carbon footprint of the protein (De Boer *et al.* 2014). Thus, solutions should be explored such as e.g. more efficient drying techniques or a change in feeding concepts from wet feeding. With regard to insects, only very few studies have been made. The study on mealworms resulted in a very high carbon footprint for the larvae protein, mainly due to the high-energy requirement during rearing and the drying step thereafter, plus the use of feed ingredients as feedstock. The use of other insect species with a lower energy requirement during rearing and using waste products instead of feed ingredients should be explored.

Furthermore, in order to perform comprehensive comparisons between alternative protein sources, the LCA methodology needs to be available, improved and developed and the data on the processes should be available.

With regard to the data, the availability of input and output data and emissions from bioreferineries, insect rearing plants, aquatic environments etc. is essential, but the data acquisition might be challenging since it is a new and developing area.

With regard to the LCA methodology, all relevant impact categories should be included, such as impacts on climate change (including land use change), eutrophication, biodiversity, water, toxicity etc. At the moment, some of the impact categories are under development such as impact with regard to biodiversity, water and land use change. The methodology on land use and land use change is currently developing and hotly debated and will be crucial in the environmental assessment of the alternative protein sources since some of them are using land and others are not. Furthermore, the positive removal of nutrients from the sea should also be included, which is a challenge since LCA is mainly focused on emissions and resource consumption. Some of the impact categories have a global impact, such as global warming, whereas others have a more local impact, such as eutrophication and removal of nutrients plus biodiversity, which have more local or regional impact. Traditionally, this has not been taken into account in LCA's, but for European politicians this might be relevant to include, so the life cycle assessments take the geographical distribution of resource consumption and emissions into account. Finally, there is a need to improve the methods when studying supply chains where the output is not one product, but a wide range of products such as in biorefineries. The existing methods are most suitable to situations where you can define "a main product" (and perhaps a number of by-products). The existing methods, e.g. described in the leading standards such as ISO standard for life cycle assessment, JRC ILCD handbook as well as in European Food Sustainable Consumption and Production (SCP) Roundtable, are not suitable for this purpose and there is a need for methodological development within this area.

10.9 Conclusion and Recommendations

One of the major concerns of the import of soymeal for the European livestock sector is the environmental issues. Alternative protein sources have been suggested such a marine biomass, agricultural biomass in combination with biorefineries, insect protein and single cell protein. In order to assess and compare the environmental impact of alternative protein production in Europe, life cycle assessment is one of the best and most widely used tools. However, few LCA studies have been conducted so far on alternative protein sources. A few hotspots have been identified, such as the drying process and the high rearing temperature for rearing insects. The use of organic waste and sidestreams as a biomass feedstock is also promising. There is a huge need for more LCA studies on alternative protein sources in order to compare and develop the production processes of alternative protein. There is also a need for methodological development of the LCA methodology for the new production processes. Due to the very few LCA studies made on alternative protein sources so far, no conclusions should be made yet on the environmental impact of those protein sources, before more LCA studies are available. Specifically, there is a huge demand for more LCA studies on protein from grass/clover, marine biomass, insects and single cell proteins.

10.10 References

Ahlgren, S., Björklund, A., Ekman, A., Karlsson, H., Berlin, J., Börjesson, P., Ekvall, T., Finnveden, G., Janssen, M., & Strid, I. (2015). *Review of methodological choices in LCA of biorefinery systems - key issues and recommendations.* Biofuels, Bioproducts and Biorefining (in press). http://dx.doi.org/10.1002/bbb.1563

Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., & Williams, A. (2009). *How Low Can We Go? An Assessment of Greenhouse Gas Emissions from the UK Food System and the Scope to Reduce them by 2050*. WWF-UK.

Baumgartner, D.U., de Baan, L., & Nemecek, T. (2008). *European Grain Legumes - Environment-Friendly Animal Feed? Life Cycle Assessment of Pork, Chicken Meat, Egg, and Milk Production Grain Legumes Integrated Project (GLIP)*. New Strategies to Improve Grain Legumes for Food and Feed Food Quality and Safety; WP2.2: Environmental.

Bosselmann, A. S., & Gylling, M. (2014). *Miljømæssige konsekvenser ved den danske import af majs og soja til svinefoderproduktionen*, 11 s. (IFRO Udredning; Nr. 2014/20).

BSI (2011). *Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services.* PAS 2050:2011. Retrieved from http://www.bsigroup.com/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050

Consito (2014). *Klimagevinster ved øget proteinproduktion i Danmark*. Retrieved from http://concito.dk/files/dokumenter/artikler/protein_rap_270114.pdf

Cherubini, F., & Jungmeier, G. (2010). LCA of a biorefinery concept producing bioethanol, bioenergy, and chemicals from switchgrass. *Int. J. Life Cycle Assess. 15* (1): 53–66. http://dx.doi.org/10.1007/s11367-009-0124-2

Dalgaard, R., Schmidt, J., Halberg, N., Christensen, P., Thrane, M., & Pengue, W.A. (2007). LCA of soybean meal. *International Journal of Life Cycle Assessment 15*: 1–15.

De Boer, H.C., Van Krimpen, M.M., Blonk, H., & Tyszler, M. (2014). *Replacement of soybean meal in compound feed by European protein sources*. Effects on carbon footprint. Livestock Research Report 819.

De Souza, D.M., Teixeira, R.F.M., & Ostermann, O.P. (2014). Assessing biodiversity loss due to land use with Life Cycle Assessment: are we there yet? *Global Change Biology 21*(1): 32–47. http://dx.doi.org/10.1111/gcb.12709

European Commission, DG ENV (2013). *The impact of EU consumption on de-forestation: Comprehensive analysis of the impact of EU consumption on de-forestation.* Retrieved from http://ec.europa.eu/environment/forests/pdf/1.%20Report%20analysis%20of%20impact.pdf

FAO (2014). Accessed January 2015. Retrieved from http://www.fao.org/fileadmin/user_upload/benchmarking/docs/vellinga_feedprin_project.pdf

Gatrell, S., Lum, J., & Lei, X.G. (2014). Potential of defatted microalgae from the biofuel industry as an ingredient to replace corn and soybean meal in swine and poultry diets. Nonruminants nutrition symposium. *J. Anim. Sci. 2014.92*:1306–1314. http://dx.doi.org/10.2527/jas2013-7250

Hermansen, J.E., Knudsen, M.T., & Sørensen, J. (2014). *Soy and palm oil - Certification schemes for documenting production sustainability*. Retrieved from http://web.agrsci.dk/djfpublikation/index.asp?action=show&id=1171

Iribarren, D., Moreira. M.T., & Feijoo, G. (2010a). Life cycle assessment of fresh and canned mussel processing and consumption in Galicia (NW Spain). *Resources, Conservation and Recycling 55* (2010) 106–117. http://dx.doi.org/10.1016/j.resconrec.2010.08.001

Iribarren, D., Moreira. M.T., & Feijoo, G. (2010b). Revisiting the life cycle assessment of mussels from a sectorial perspective. *Journal of Cleaner Production 18* (2010) 101–111. http://dx.doi.org/10.1016/j.jclepro.2009.10.009

ISO 14044:(2006). *Environmental management – Life cycle assessment – Requirements and guidelines*.

Knudsen, M.T., Hermansen, J.E., Olesen, J.E., Topp, C.F.E., Schelde, K., Angelopoulos, N., & Reckling, M. (2014). *Climate impact of producing more grain legumes in Europe.* Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector.

Leinonen, I., Williams, A.G., Waller, A.H., & Kyriazakis, I. (2013). Comparing the environmental impacts of alternative protein crops in poultry diets: The consequences of uncertainty. *Agricultural Systems 121* (2013) 33–42. http://dx.doi.org/10.1016/j.agsy.2013.06.008

Mogensen, L., Kristensen, T., Nguyen, T.L.T., Trydeman Knudsen, M., & Hermansen, J.E. (2014). Method for calculating carbon footprint of cattle feeds – including contribution from soil carbon canges and use of cattle manure. *Journal of Cleaner Production xxx* (2014) 1–12. http://dx.doi.org/10.1016/j.jclepro.2014.02.023

Oonincx, D.G.A.B., & De Boer, I.M.J. (2012). Environmental Impact of the Production of Mealworms as a Protein Source for Humans – A Life Cycle Assessment. *PLoS ONE 7*(12): e51145. http://dx.doi.org/10.1371/journal.pone.0051145

Parker, R. (2012). *Review of life cycle assessment research on products derived from fisheries and aquaculture: a report for seafish as part of the collective action to address greenhouse gas emissions in seafood*. Sea Fish Authority.

Schmidt, J.H., Weidema, B., & Brandão, M. (2015). A framework for modelling indirect land use changes in Life Cycle Assessment. *Journal of Cleaner Production 99*: 230–238. http://dx.doi.org/10.1016/j.jclepro.2015.03.013

Sills, D.L., Paramita, V., Franke, M.J., Johnson, M.C., Akabas, T.M., Greene, C.H., Tester, J.W., (2013). Quantitative uncertainty analysis of life cycle assessment for algal biofuel production. *Environ. Sci. Technol. 47*:687–694. http://dx.doi.org/10.1021/es3029236

Spångberg, J., Jonsson, H., Tidaker, P., (2013). Bringing nutrients from sea to land – mussels as fertilizer from a life cycle perspective. *Journal of Cleaner Production 51* (2013) 234–244. http://dx.doi.org/10.1016/j.jclepro.2013.01.011

Termansen, M., Gylling, M., Jørgensen, U., Hermansen, J., Hansen, L.B., Knudsen, M.T., Adamsen, A.P., Amby, M., Jensen, S.K., Andersen, H.E., & Gyldenkærne, S. (2015). *Notat om grøn biomasse til det nationale bioøkonomipanel.* Notat the DCE, Nationalt Center for Miljø og Energi. 26.

Thrane, M., & Schmidt, J., (2004). Life Cycle Assessment (LCA). Chapter 12 in: Arler F., Kornov, L., Remmen, A., (eds.) *Tools for Sustainable Development*, Department of Development and Planning, Aalborg University.

Thrane, M., (2006). LCA of Danish fish products. *International Journal of Life Cycle Assessment*, vol 11, nr. 1, 66–74., http://dx.doi.org/10.1065/lca2006.01.232

Van Krimpen, M.M., Bikker, P., Van der Meer, I.M., Van der Peet-Schwering, C.M.C., & Vereijken, J.M. (2013). *Cultivation, processing and nutritional aspects for pigs and poultry of European protein sources as alternatives for imported soybean products*. Report 662, Wageningen UR Livestock Research, Lelystad, The Netherlands.

Van Zanten, H.H.E., Ooninccx, D.G.A.B., Mollenhorst, H., Bikker, P., Meerburg, B.G., & De Boer, I.J.M., (2014). *Can the environmental impact of livestock feed be reduced by using waste-fed housefly larvae?* Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector.

Veldkamp, T., Van Duinkerken, G., Van Huis, A., Lakemond, C.M.M., Ottevanger, E., Bosch, G., & Van Boekel, M.J.A.S. (2012). *Insects as a sustainable feed ingredient in pig and poultry diets – a feasability study.* Report 638, Wageningen UR Livestock Research, Lelystad, The Netherlands.

WWF (2014). *The growth of soy. Impacts and solutions.* WWF International, Gland, Schweiz.

11. Local Protein Challenges from a Farmers Perspective

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11.1 Introduction

In this chapter, local protein production with focus on Latvia is described. This includes a farmer's point-of-view. In order to understand the current situation in Latvia, a historical interpretation/perspective is also included. Local conditions (geographical, land, climate) and adequacy for local protein production is considered. Some alternative protein sources as earthworm and mussels are developing, while still they are not ready for playing an important role in the protein sector in the region. Recommendations from the farmer's perspective are elaborated in the following section, covering practical and policy development needs.

11.2 A Farmer's Perspective

Protein is an expensive nutrient in animal feed ratio and, therefore, often a limiting factor for achieving maximum productivity. Protein cropping on farm is not typically perceived from the perspective of only protein production per hectare (Chadd, Davies and Koivisto 2002). In practice, the unit cost of protein is clearly important for the competitiveness and commercial viability of a livestock enterprise. Farmers usually do not think about the unit cost of homegrown protein, when planning cropping programs and their farm business. They are more concerned about their whole farming system planning; farm resources; how well a crop fits into the rotation and in particular, for arable legume crops, what the financial output reflected in the gross margin might be. In the same way, and from a similar broad farm business perspective, a livestock farmer may judge a homegrown crop mostly on the basis of the contribution it will/can make to the animal feeding program. Besides economic effects of animal feeding, local protein crops are characterised by its ability to contribute to landscape improvements, nitrogen management, reduced pests and disease pleasure (EIP-AGRI Focus Group 2014).

11.3 Situation with Imported Proteins in Latvia

Animal breeders in Baltic States mainly use imported soymeal and maize protein sources. Since 2010, imported soy (beans and meal) quantity slightly decreased from 143 to 110 thousand tons respectively in 2011. However, the volume of imported maize since 2010 is slightly increasing (Lakovskis, Benga and Mikelsone 2013). Nearly all imported maize and soy is genetically modified. The demand for less expensive sunflower products is growing, which leads to increased import volumes.

The soy is imported (indirectly) from Lithuania, the Netherlands and Germany, but corn – mainly from Lithuania, USA, Ukraine and Argentina. Soy is not cultivated in Europe (just low amounts in Germany) but comes from the large-growing countries. At present, imported soy and corn are relatively expensive, so that the farmers would benefit by similar (self-produced) energy or protein-based animal feed.

Until now, the view has been that GMO-containing feed is the cheapest and most cost-effective source of protein that has no alternative (Orupe 2012). Those who have grown non-GM feed for their own use, confirm that it contains the necessary nutrients, and such food reduces the final production costs. There is thus a potential to replace soy proteins for animal feed with locally produced protein in Latvia.

11.4 Unexploited Land in Latvia as Potential Resource for Protein Production

In recent years, the issue of utilised agricultural area and its accessibility for production has gained increased importance. If we look into the history in 1938, the total arable area in Latvia was 1,877,4 thousand ha. The arable area in Latvia remained nearly constant till 1990 (1,627 thousand ha). After the collapse of the Soviet Union, when political, economic and structural changes occurred in country, arable area started to decline very rapidly, reaching 930,00 thousand ha in 1995 and the lowest point was reached in 2003 – 851,00 thousand ha. At that period agricultural land overgrew with weeds and bushes and land bogging occured. From 2006, the recovery of economic activity in agriculture has started and in 2014 cultivated land reached 1,150,000 thousand. ha. In the last couple of years overall recovery of agriculture land has occurred in Latvia by deforestation, bush harvesting and reconstruction of drainage. The objective set by National Development Program is to reach 2 million ha agriculture area by 2020.

11.5 Currently Available Local Sources of Proteins in Latvia

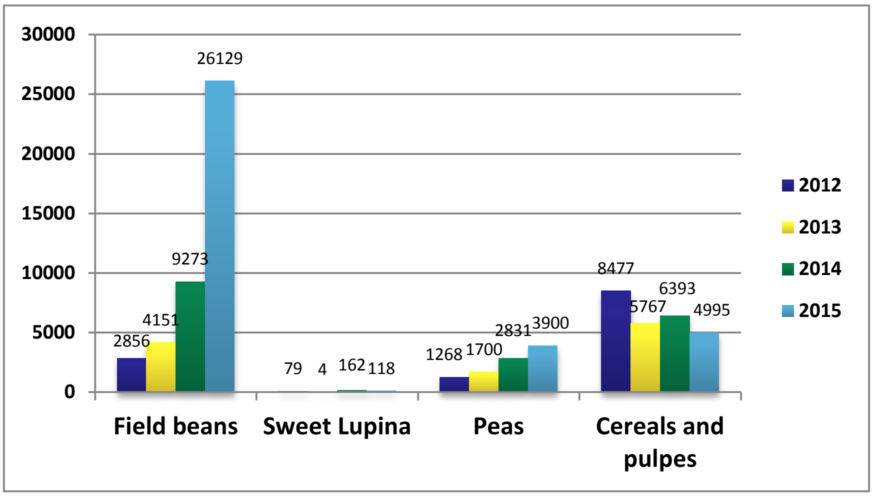
11.5.1 Legumes

Alternative protein sources that can be successfully grown in Baltic countries are legumes, – peas, beans and vetch. According to the Latvia Rural Support Service data from 2012, the total area of cultivated legumes has increased more than double. Latvian farmers have long-term legume growing traditions. In Soviet times, protein plants where considered as part of crop rotation. However, in the last years, due to greening requirements of the revised EU Common Agriculture Policy (CAP), the area of legume cultivation has dramatically increased in the Baltic countries.

Legumes (fodder beans and peas) have a high protein content, a balanced amino acid profile and good digestibility. Legumes offers a high content of carbohydrates (starch), a high energy content for ruminants (~12 MJ), a low content of fat, fiber and lignin and a low level of waste material. The content of nutrients is relatively constant.

The area of field beans in Latvia dramatically increased in 2015, if compared with 2013, reaching 1.62% of the area declared for Single Area Payment in Latvia. The area used for cultivation of sweet lupine, cereals and pulses in the last two years has slightly declined. The area for pea cultivation has slightly increased. Dramatic growth observed for field beans ha in 2015 is the result of a new Common Agriculture Policy Greening requirement.

Table 16: Legume area dynamics in Latvia (ha)



Source: Data from Latvia Rural Support Service.

Specific legume growing conditions in Latvia (Zute, Aplocina and Zarina 2015):

- Legume yields are affected by weather conditions and they vary greatly per year. It depends on the temperature and humidity during pods formation period.
- Additional fertiliser norms give positive impact on legume growth and development, because they demand certain nutrients – phosphorus, potassium, sulfur, boron, molybdenum.
- The yield for legumes is lower than for cereals, which makes farmers focus more on cereals.
- Late harvest is an obstacle due to wet and cold conditions in autumn.
- Beans and peas are highly affected by different diseases and pests (crop rotation after 4–6 years).

The high increase of the legumes ha may also cause some unexpected problems for local farmers. Farmers have sown protein cultures because of greening requirements, however, the fodder production companies have not changed or introduced recipes with the locally produced proteins. This gives challenges to the farmers in relation to rearranging their feeding systems to locally produced protein crops.

11.5.2 Linseed

A high quality source of protein is chopped linseed. They are fibre-rich and serve great to regulate metabolism, strengthen immunity and improve the functioning of the digestive system. It contains mucilaginous substances and polyunsaturated fatty acids Omega-3 and Omega-6. The area used for cultivation of linseed in Latvia increased from 221 ha in 2009 to 1,406 ha in 2011. Flax yield of 2009 compared to 2011, increased by 3.7 quintals per ha. Oil industry by-products, linseed cake or oil meal can be successfully used in animal feed.

Several field trials have been conducted in Latvia in order to evaluate the locally produced proteins influence on the animals' productivity. The studies of Latvian Rural Advisory Centre (2012) showed a small but relative insignificant increase in the pork and milk production price. In the case of egg production, costs is the same, but the chicken meat production is much cheaper. In comparison with imported GMOs, feed use of local feed resources is nationally economically advantageous as they are supported by local producers. A study by Agriculture University experts' (Aplocina and Veipa, 2015) showed that including of beans in feed ration did not lead to an increase in goat milk productivity, however, a significant decrease in the number of milk somatic cells by 29% was noticed. In all cases, the most convenient is feed with self-produced components. Furthermore, the farmer is less dependent on the feed market price fluctuations. By producing protein rich feed locally, it is thus possible to reduce production costs, improve the nutrient balance of the farm, as well as to improve land use sustainability.

11.5.3 Earthworm

One of the possibilities to balance the ration of animals and provide them with animal protein is the earthworm breeding (Spruzs 2012). Earthworms are suitable for feeding bulls, pigs and birds as live, boiled or dried form. Earthworm growing as an innovative business activity has recently been introduced in Latvia. Earthworm growing is still in the initial phase of business development and trials and activities are ongoing. The company Ltd "Daga" in Ventspils district conducted a trial with laying hens by including earthworms in the feed. A 50 day trial including 14 g earthworm in the feed, gave the following economic effects:

- Forage demand decreased by 13%.
- Chicken egg-laying rate increased by 6.8%.

- The average egg mass increased by 5.2%.
- Content of carotenoids in the hen's eggs increased by 5.5%.

11.5.4 Aqua Protein

Fish is a vital source of proteins, minerals, and healthy fatty acids. Small pelagic fish, which are unattractive for human consumption, and trimmings from the fish processing industry are primarily used for fishoil and fishmeal production. Blue mussels (Baltic EcoMussel Project 2013), which cannot be used for human consumption, can be used for fish feed production. The second step in the chain is the manufacture of fishmeal and fish oil from the industrial fish and the processing of raw materials to extract fatty acids, proteins, and starch. From one-kilo industrial fish, 3–5% fish oil and 20–25 % fishmeal can be obtained, the rest is water. Since mussels are at the second step of the marine food-chain, the use of mussels instead of fish for feed production is of large ecological importance at a time when many fish-stocks are over-exploited on local/regional and global scales. In Latvia at this stage only fishmeal is produced. Mussels growing business is only at the study stage.

11.5.5 Stakeholders' Interest and Business Potentials

In order to facilitate local protein production and generate business development, co-operation is needed between the feed industry, breeding industry, farmers, research and advisory, government and NGOs. The cooperation through ongoing research projects in Latvia has already started and entrepreneurs are looking forward to the first results. Especially, since research and demonstration activities are based on local climate, geographical and production conditions. A number of on-going projects and initiatives in Latvia focus on protein production:

- Ministry of Agriculture supported research projects (e.g. "Legumes – alternative protein source for fodder production – growing agro-technical and economic feasibility in Latvian conditions)", implemented by State Stende Cereals Breeding Institute and State Priekuli Breeding institute.
- EU supported projects – FP7, "Enhancing of legumes growing in Europe through sustainable cropping for protein supply for food and feed", State Priekuli Breeding institute. Rural Advisory and Training Centre Demonstration project activities, which are implemented as applied research activities.

- Activities of NGOs, local action groups against GMO and support of locally produced food.

The first studies have evaluated local conditions on the aqua protein production and use. However, there is no information available on the business level of aqua protein production in Latvia, as well as wide research and studies on the possibilities. The waste materials from fish processing are currently mainly used at biogas plants and mink farms.

Earthworm farming developed when investments in earthworm farms where supported by the Rural Development Program in 2012–2013. However, due to lack of knowledge and small experience, there is not a high economic potential observed for earthworm farms. The main products currently are biohumus, which is marketed as a high nutritive value soil material. Earthworms may also be sold to other interests who use them for transformation of organic waste into biohumus.

11.6 Opportunities and Constraints

There is number of protein crops that could have a good potential to increase the protein production in Baltic countries and at the same time increase sustainability and reduce supply risks for the compound feed industry. Although the variety of potential protein crops is wide, due to specific agro-climatic zone conditions, it is necessary to focus on a limited number of crops, as financial resources will be limited. The total innovation process will require many years, keeping in mind the fail factors and the opportunities.

Currently, the competitiveness gap for protein crops is high. In order to make protein crops more attractive for the farmers, complex development actions are needed:

- Breeding programs targeted to the increase of yields – yields of protein crops are more variable as those of cereals and maize. Therefore, new varieties, adapted to the local conditions of the Baltic region are expected.
- Agronomic technologies development and adaptation for the region. Not only pure protein crops, but also possibilities to use mixed cropping to increase combined yield per ha must be considered. Incorporation of the proteins in crop rotation should be strengthened.
- Technologies and information for plant protection measures need development, especially in the conditions when discussions about

application and/or restriction of different crop protection substances (pesticides) are growing in Europe.

- Protein crops influence on the nitrogen rotation cycle and other processes in the soil require deeper studies.
- Policy instruments facilitating protein crops. Protein crops are strongly supported by the Greening Measure in the EU CAP Reform. Under the new EU CAP, farmers in the member states have to comply with mandatory greening measures to qualify for 30% of their new basic payment from 2015 onwards. One of the basic measures is crop diversification. The crop diversification oblige farmers to grow at least three different crops, with the largest crop covering no more than 70% of the farm holdings' area and the smallest no less than 5%. Additionally, EU member states are entitled to use part of their National Ceiling to introduce a coupled aid for protein crops to counteract the huge dependence in the EU on imported protein for use. At EU level, the policy elaboration process should look at the entire value chain (including production, harvesting, processing, consumption at industrial or household level, environmental aspects, etc.), which can be influenced by policy decisions. Policy should be planned with direct focus on regions, considering specific conditions and influences in all related value chains. E.g. in relation to the situation with beans and peas we can observe, that there is a growing number of ha, but there are no clear conditions for harvest, treatment, processing and consumption.
- Lack of information and knowledge for the farmers and advisors about profitable methods of protein crop production. Information should be developed through research and innovation networks: from research – to farmers, EIP operational groups, etc.
- Knowledge on pre-treatment and processing methods for the beans and peas. Evaluation of feed value of the different types of feed, with focus on the needs of particular animal groups. Treatment methods must be adapted.
- Innovative protein sources such as earthworm and aqua protein are currently niche products in Latvia with a growing export potential. At present, there is no local knowledge support for the sectors due to the low available and specific need of scientific capacity.

11.7 Conclusion

From a farmer's perspective, protein is the most expensive nutrient in feeding and, therefore, often a limiting factor for maximum productivity. There are different sources of protein for animal feed available, however, they must be adjusted to become suitable for different sizes of farms: industrially large scale processing (e.g. oil rich crops, rapeseed), (e.g. starch-rich, such as peas and beans) for small scale and ready usable on farms with minor processing. When focusing on the economic aspects of the local proteins, producers of the region are focusing more and more on reducing feeding costs per day, rather than optimising feeding efficiency. The cheapest ration is not always the most production-efficient ration. Focus should be on education and knowledge on how to balance the feed, how to calculate the feeding norms, how to reduce the costs as well as balancing the production cost efficiency.

More research is recommended in the agronomy as well as further development of alternative and novel protein production. Also support must be focused for longer-term strategies of crop development and improvement, through breeding and genetic practices. Furthermore, meaningful and greater co-operation is advocated between policy-makers, the feed industry, farmers and researchers to better deliver the future protein supply potential.

From an animal husbandry perspective, new feeding strategies, utilising alternative protein sources, needs more detailed studies, with respect to the nutrition and also economic aspects.

New developments and studies in local protein perspective are vitally important in relation to environmental and climate change mitigation aspects, considering both – agronomy and feeding practices. Farmers can be seriously affected by new requirements for climate change reduction target fulfillment. Therefore, the potential of alternative protein sources should be evaluated in the close context of climate change.

All farming activities in EU countries are strongly affected by political decisions and regulatory acts, therefore, in the process of local protein production and consumption development, all elements of the value chain must be considered.

Production of protein in practice has considerable future potential, with no shortage of possible supply routes. Realising the potential, however, from research to farm and feed manufacturer requires considerable investment, knowledge and cooperation capacity.

11.8 References

Aplocina, E., & Veipa, L. (2015, June). *Including of Field Beans as Protein Source in Feed Ration for Dairy Goat*. Paper presented at the 7th International Conference on Chemical, Ecology and Environmental Sciences, ICCEES'2015, Pattaya, Thailand.

Baltic EcoMussel project. (2013). *Mussel Farming the New Baltic Sea Aquaculture Industry*. Retrieved August 21, 2015, from http://www.kurzemesregions.lv/userfiles/files/1384854084_Brochure_popular%20text.pdf

Chadd, S.A., Davies, W.P., & Koivisto, J.M. (2002, May). *Practical production of protein for food animals*. Paper presented at Food and Agriculture Organization of the United Nations Expert Consultation and Workshop, Bangkok, Thailand.

EIP-AGRI Focus Group. (2014). *Protein Crops: final report*. Brussels, EIP-AGRI Service Point.

Lakovskis, P., Benga, E., & Miķelsone, Z. (2013, February). *Platību maksājumu nozīme lauksaimniecības zemes izmantošanā*, Paper presented at Scientific Conference Agriculture Research for Successful Farming, Jelgava, Latvia.

Lauku atbalsta dienests. (2015). *Platību maksājumi*. Retrieved August 20, 2015, from http://www.lad.gov.lv/lv/statistika/platibu-maksajumi/

Orupe, A. (2012). *Eksperti pēta, kā pabarot bez ĢMO*. Retrieved August 21, 2015, from http://nra.lv/latvija/83948-eksperti-peta-ka-pabarot-bez-gmo.htm

SIA Latvijas Lauku konsultāciju un izglītības centrs, Zemes Draugi. (2012). *Par ģenētiski modificētus organismus (ĢMO) nesaturošas dzīvnieku barības ražošanas iespējām un izmaksām*. Ozolnieki, LLKC.

Spruzs, J. (2012). *Slieku audzēšana un izmantošana*. Paper presented at Scientific Conference Agriculture Research for Successful Farming, Jelgava, Latvia.

Zute, S., Aplocina, E., & Zarina, L. (2015). *Pākšaugi - alternatīva sojas izmantošanai proteīnbagātas spēkbarības ražošanā: Audzēšanas agrotehniskais un ekonomiskais pamatojums Latvijas apstākļos*, Retrieved August 21, 2015, from http://www.stendeselekcija.lv/jaunumi/data/augsuplades/files/Pākšaugi%20ZM%20512_2014.pdf

12. Nordic Added Value of Alternative Feed Protein Potentials in the Nordic and Baltic Sea Region

Bioeconomy has been high on the agenda of Nordic cooperation during the recent years. Various studies on Nordic bioeconomy include e.g. Nordic Innovation (2014) on Nordic bioeconomy resources, Nordregio (2014) on Regional state-of-the-art and potential of Nordic bioeconomy, and Matis (2014) on bioeconomy in Iceland, Greenland, and Faroe Islands. The Nordic studies on bioeconomy have been complemented by Nordic & Baltic mapping of bioeconomy actors (2014) by the Nordic Council of Ministers. The Nordic sustainable protein production initiative takes the previous studies on Nordic & Baltic bioeconomy as one point of departure, and makes an attempt to focus on increasing cooperation between relevant actors in the field of sustainable proteins in Nordic and Baltic countries and regions.

The Nordic/Baltic Sea region sustainable protein production initiative has contributed to creation of Nordic added value at least in the forms of joint learning, joint sharing of good practice experiences, and dissemination of results. Moreover, the project has been able to build a bridge between Nordic actors and Baltic Sea region actors.

Joint Nordic learning has included several joint workshops, meetings, and phone/Skype sessions in order to gain a better understanding of the field of proteins in a Nordic and Baltic context. The multidisciplinary constellation of the project group, including representatives from universities, research institutes, technology parks and relevant associations has resulted in a broader understanding of the nature and potential of proteins in Nordic and Baltic Sea region countries and regions.

Joint sharing of good practice experiences has included presentations and discussions on good practice cases related to Nordic and Baltic Sea region protein-related initiatives, e.g. side stream potentials, pilot experiments in research centres, and projects aiming at better utilisation of existing protein sources. The awareness of experts in the field of proteins has been broadened within the Nordic region as well as throughout the Baltic Sea region.

The dissemination of the results of the project includes, besides the final report, information shared at the workshops (especially the workshop in Denmark on June 16, 2015). The project report deserves a wider dissemination even outside the Nordic/Baltic Sea region, to provide a brief presentation on Nordic/Baltic Sea region actors and their plans in the field of proteins. The project has been able to identify, share and utilise documents and project reports from other sources, too, including valuable data on protein sources.[1]

The project has been able to prepare a joint framework for a more in-depth mapping/analysis of the Nordic and Baltic Sea region protein sources and their potential. The implementation of the mapping exercise in the regions would be a necessary following step towards more in-depth quantitative and qualitative understanding of the true potential of current and planned sustainable protein initiatives.

The value and importance of increased human interaction between the Nordic and Baltic Sea region experts participating in the project should not be underestimated. The official and unofficial meetings and contacts with the participants of the project have prepared the ground for future joint initiatives in the field of proteins. The increased mutual understanding of the experience, skills, and potential of project participants makes it considerably easier to consider joint initiatives e.g. EU Horizon programme initiatives in the near future. The Nordic Council of Ministers is a valuable and natural partner in the future development of Nordic cooperation in the field of sustainable proteins.

[1] See e.g. EU FP7 ARRAINA project report on aquaculture feed ingredients: http://arraina.eu/images/ARRAINA/Media_Center/ARRAINA%201st%20Booklet%20Feed%20Ingredient%20Database.pdf

12.1 References

Matis (2014). *Future Opportunities for Bioeconomy in the West Nordic Countries*. Matis Report. Retrieved 30 May, 2015, from http://www.matis.is/media/matis/utgafa/Bioeconomy-in-the-West-Nordic-countries-37-14.pdf

Nordic Council of Ministers. (2014). *A Bioeconomy for the Baltic Sea Region: Mapping of stakeholders, practices and opportunities*. Retrieved 2 May, 2015, from http://scanbalt.org/files/graphics/Illustrations/BSR%20BIOECONOMY%20MAPPING%20-%20final.pdf

Nordic Innovation. (2014). *Creating value from bioresources. Innovation in Nordic bioeconomy*. Nordic Innovation report 2014:01. Retrieved 2 May, 2015, from http://www.nordicinnovation.org/Publications/creating-value-from-bioresources-innovation-innordic-bioeconomy/

Sammenfatning

Denne rapport er en sammenfatning af diskussioner og skriftlige bidrag fra en gruppe af forskere og eksperter fra forskellige fagområder. Koordineringen og redigeringen af rapporten er udført af Agro Business Park i tæt samarbejde med de deltagende partnere. Hver partner er blevet bedt om at bidrage med skriftligt materiale (et afsnit/kapitel) inden for deres specifikke fagområde. Dette materiale er præsenteret til to interne workshops samt ét offentligt seminar. De skriftlige og mundtlige bidrag er efterfølgende blevet redigeret og sammenfattet til denne rapport.

Partnerskabet bestod af Nordregio (Sverige), Swedish University of Agricultural Sciences (Sverige), Latvian Farmers Parliament (Letland), Maritime Institute in Gdansk (Polen), Matis Ltd (Island) og de fire danske partnere: Københavns Universitet, Aarhus Universitet, AgroTech Holeby (tidligere Grønt Center) samt Agro Business Park.

Formålet med det udarbejdede materiale er at skabe et fundament for yderligere studier og aktiviteter omkring den bio-økonomiske udfordring omhandlende erstatning af importerede sojaprodukter, som ikke er produceret under bæredygtige betingelser med lokale og bæredygtige proteinkilder. Realisering af dette vil betyde ændringer i husdyr- og akvakulturproduktionen, hvilket kræver teknologisk innovation samt omfattende og forskning og udvikling. Målet med denne rapport er at klarlægge de næste nødvendige skridt.

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Nordic Alternative Protein Potentials

Within agri- and aquaculture, a specific bioeconomy challenge – and a bioeconomy opportunity – has been identified concerning sustainable protein supply for livestock production and fish farming. Today, imported soy products are by far the most important protein source however several alternative ways of producing protein rich feed has been identified using regional resources. Production of legumes, pulses and grass can be expanded. Alternative protein rich sources include single cell protein (bacteria/fungi), macroalgae (seaweed), mussels and insects. Local protein production has a number of benefits in the form of generation of local jobs, reduction in the import of nutrients and in general boosting the bioeconomy. Many of the alternative ways of producing protein rich feed are still under development, this report therefor also includes recommendations concerning how to proceed.

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