Green biomass

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Scientific report

The reports contain mainly the final reportings of research projects, scientific reviews, knowledge syntheses, commissioned work for authorities, technical assessments, guidelines, etc.

Preface

The present report provides an overview of the major potentials and challenges in relation to production of green biomass in Denmark and gives scientific input to the National Bioeconomy Panel's discussions on the potentials of green biomass. The report has been commissioned by the Danish AgriFish Agency as part of the "Contract between Aarhus University and the Ministry of Food, Agriculture and Fisheries on the provision of research-based public-sector services etc. by Aarhus University, DCA – Danish Centre for Food and Agriculture, 2015 – 2018" (item BL-104 in Annex 2 of the Contract).

Special thanks are extended to the authors of the report, and to Lene Lange, the Danish Technical University; Michael Støckler, SEGES; Klaus K. Nielsen, DLF-Trifolium; Gitte Blicher-Mathiesen, Aarhus University and Jørgen E. Olesen, Aarhus University for their contributions.

Niels Halberg
Director, DCA – Danish Centre for Food and Agriculture

Introduction

There are 2.6 million hectares of agricultural land in Denmark, indicating that around 60 % of the total area is allocated to agricultural production. The dominating crop in Danish agriculture is cereal grains which are grown on 1.4 million hectares. The second most widespread crop type is grass and green fodder which occupy 0.6 million hectares. As 77 % of the cereal grain production is used for feed this implies that the share of agricultural land used for producing animal feed by far exceed the share used for producing products for human consumption. Despite the significant share of farmland allocated for feed production, Denmark imports approx. 1.5 million tonnes of soy meal every year; this is equivalent to around 5 % of the total European import of soy meal. Soy meal is a by-product of oil extraction, and it is typically used in compound feed to increase the protein content. Apart from representing a financial cost, the import of soy meal also gives rise to environmental and social concerns. Hence, the soy meal production, which primarily takes place in South America, is often associated with environmental degradation such as the clearing of forest land, and it is also known to cause health and social problems for local populations Consequently, alternatives to the import of soy meal are welcome, and green biomass which has a higher yield and higher protein content than grain may represent a relevant substitute. The potential for green biomass to act as a substitute for the imported soy meal is, however, contingent on the technical and economic feasibility of extracting the protein from the green biomass. Apart from this green biomass also holds considerable potential as an input to the production of high-value products for feed and consumption. Finally, it is noted that a conversion from cereal grain production to grass-based production is associated with a range of potential environmental benefits. These potentials give the motivation for analysing technical, economic and environmental aspects of green biomass production in this report.

Contents

Background description

Green biomass: Production potential

In the plan for increased availability of biomass in Denmark (The +10 million tonnes study; Gylling et al., 2013) the division of biomass into green, yellow, blue, brown, black and grey types was used for illustrative purposes. Green biomass is the term used for a living, herbaceous (contrary to ligneous) and wet (contrary to mature/dry) biomass. There is no precise scientific definition as to which biomasses are considered green, but in practice it is usually obvious whether or not a certain biomass belongs to the green ones. Green biomass comprises e.g. grass, clover, beets and whole crop.

In the present production of grain and rapeseed a significant part of the solar radiation during the growth season is not used for photosynthesis and biomass production. The reason for this is the fact that crops are ripening from mid-July, harvested in August, re-sown in September and green fields are not seen until the very end of the year. Regarding e.g. maize a long spring period is not utilized for production. Figure 1 illustrates the typical leaf area development in spring barley compared to the development of temperature and solar radiation during the year. By and large, it is estimated that biomass production per unit of land may be increased by 70-100 % in Danish crop production by growing crops with an extended growth season or by using a better combination of annual crops (Jørgensen et al., 2013). Recent experiments accomplished at Aarhus University confirm this estimate.

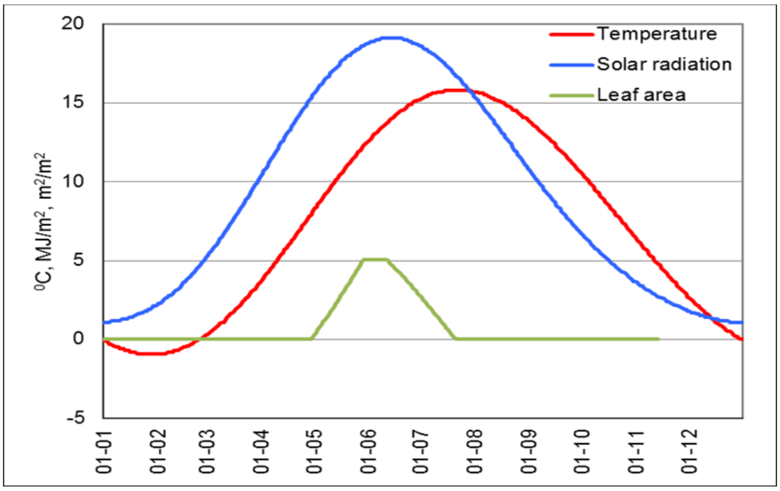

Figure 1. *Schematic diagram of photosynthetically active leaf area development in spring barley as well as temperature and (solar) radiation (modified from Olesen, 2002).*

Denmark has a well-established selection programme for grass and clover; a programme that has provided mainly cattle farms with high-yielding varieties for decades. The major aims were to achieve a significant biomass production combined with high levels of digestibility, disease resistance and persistence. Grass has a high yield potential whereas red clover is characterized by its extremely high protein content. So far, field trials with various mixtures of species demonstrated a significant variation in the total protein yield depending on mixing proportions and cultivation method. It is therefore estimated that it will be possible to increase the total protein yield from grass-clover fields by 10 % by focusing on other properties such as higher protein content and increased co-cultivation ability (estimate from DLF-Trifolium, information from Klaus K. Nielsen).

Bio-refining of green biomass

Cultivated grasses and grassland legumes may have high protein contents (up to 30 % of the dry matter) and while it is utilized optimally by ruminants (cattle and sheep), monogastrics (pigs and poultry) are only able to utilize grass to a very limited extent due to the fiber contents of grass. However, it is possible to extract and process protein from fresh grass, the quality of which is sufficient to replace soya protein in compound feeds for pigs and poultry (Houseman & Connell, 1976; Pirie NW, 1987).

At Aarhus University a pilot plant was built in the summer of 2015 with a view to optimizing and documenting protein extraction efficiencies and qualities of various crops.

Protein extraction

The protein extraction process is fairly simple. A protein extraction facility may consist of equipment for biomass feeding, comminution, fractionation (screw press and decanter) and heat treatment. Thus, three main fractions are produced: fiber fraction, protein isolate and a liquid fraction containing sugar, salts and non-protein nitrogen (NPN).

In a full-scale plant the process might be as follows: the biomass is delivered to a receiver plant designed in a way that allows 24-hour operation in the rest of the plant. The biomass is mixed and comminuted, and next recirculated water is added before the mass is pumped to one or more screw presses and separated into a fiber fraction and a liquid fraction. The fiber fraction contains about half of the protein as well as the major part of the carbohydrates. This fraction may be used as cattle feed or as raw material in ethanol production.

The liquid fraction contains about half of the protein depending on the type and maturity of the crops as well as water-soluble substances. The protein is precipitated when heated in a heat exchanger and/or by adding vapor. Next, the precipitated protein is separated in a decanter centrifuge and is termed protein isolate as its protein content is 40-50 % of the dry matter and may be used as feed for monogastrics.

After extracting the protein isolate a minor amount of residue remains – a liquid fraction containing 5-10 % organic matters, mainly readily soluble carbohydrates which may easily be fermented for ethanol or biogas production.

Figure 2 demonstrates a simplified version of the process in a decentralized plant established close to the crops and e.g. a biogas plant. Thus, the heat produced at the biogas plant during summer and which is typically in excess may be utilized, and the residual liquid may be used in the biogas plant for additional gas production. The nutrients in the residual liquid contain potassium, phosphorus and nitrogen, which are recirculated to the cultivation areas together with the degassed slurry.

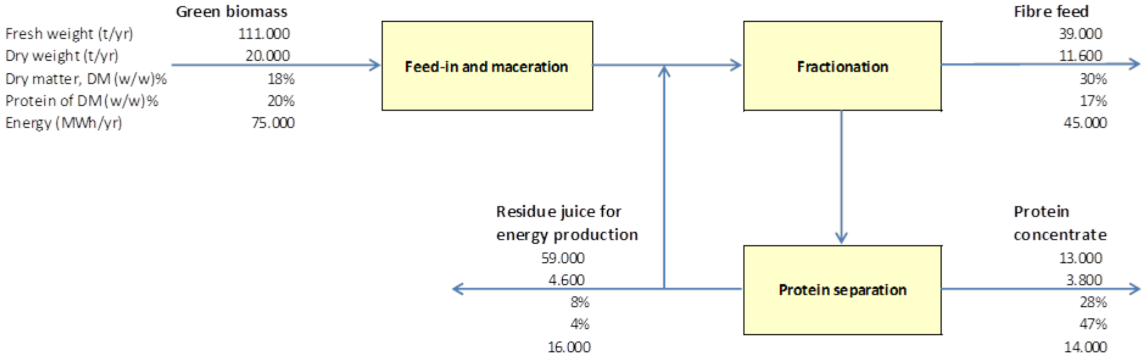

Figure 2. *Simplified process diagram for a decentralized protein extraction plant with a processing capacity of 10 tonnes of dry matter from green biomass per hour for 2,000 hours per year, i.e. 20,000 tonnes of dry matter. It produces approx. 11,600 tonnes of dry matter for cattle feed (fiber feed) containing about 17 % crude protein, and 3,800 tonnes protein isolate containing approx. 47 % crude protein corresponding to soy meal. In addition, a production of 4,600 tonnes of dry matter is produced in a residual fraction ready for processing in a biogas plant and able to produce approx. 1,150 tonnes of methane (about 1.6 million cubic meters) with an energy content of approx. 16 million kWh).*

Alternative systems

Such systems allow several possibilities for utilizing biomass. So far, preliminary evaluations have been made in relation to two systems:

- Extraction of grass/clover protein for monogastrics and use of the fiber fraction for cattle feed
- Extraction of grass protein for monogastrics and use of the fiber fraction for bioethanol

Cattle feed combination

The evaluation included yield and other consequences of converting land for cereal production to either grass (using nitrogen as fertilizer) or grass-clover production. Table 1 shows the estimated mass balance for such a system.

Table 1. *Conversion of 200,000 hectares of cereal production to production of fertilized grass, productive grass types optimally fertilized (nitrogen) or non-fertilized clover grass.*

	Standard N fertilization	**Optimal N fertilization**	**Non-fertilized productive clover grass**
Green dry matter produced	200,000 ha at 10.5 t/ha 2.1 million tonnes	200,000 ha at 15 t/ha 3 million tonnes	200,000 ha at 7 t/ha 1.4 million tonnes
Yield			
Protein isolate (soya quality)	420,000 tonnes	600,000 tonnes	280,000 tonnes
Cattle feed (grass ensilage quality)	1,200,000 tonnes	1,700,000 tonnes	910,000 tonnes
Biogas	480,000 tonnes	700,000 tonnes	210,000 tonnes
Area implications	Compared to the present production there will be a net shortage of approx. 67,000 ha for cereal production*	Compared to the present production there will be no shortage of farm land for cereal production	Compared to the present production there will be a net shortage of 100,000 ha for cereal production

*1,200,000 tonnes of cattle feed will replace 133,000 ha of roughage (grass and maize) with a yield of 9 tonnes DM/ha.

The higher yield of productive grass types (tall fescue, festulolium or cocksfoot) – achieved by increased use of nitrogen fertilization – (rather than cereal or clover grass) means that it will be possible to extract 600,000 tonnes protein feed without impacting the total area available for cereal production, if the fiber mass produced is used for cattle feed and replaces grass or maize (Table 1). However, this requires an increased application of nitrogen fertilizer approx. corresponding to the reduced N-imports of soya. Using grass-clover, which has an expected lower yield (especially if grass-clover is grown for more than two years), the technology will mean a significant shortage of cereal at national level. An additional farmland area for cereal production will be needed if standard norm fertilization is applied.

Bioethanol combination

It is presupposed that 2G bioethanol production will typically be based on straw. Next, it has been assessed how much straw may be replaced if the fiber fraction from the green biomass refining process is used for ethanol production instead of cattle feed.

Example:
10,000 hectares are used, each of 15 tonnes dry matter/ha, producing a total yield of 150,000 tonnes dry matter from grass.

After the refining process the results are

- 30,000 tonnes of protein feed of soy meal quality
- 35,500 tonnes of dry matter for biogas

The rest (85,500 tonnes of dry matter) may replace a corresponding amount of dry matter from straw and produce about 20 million litres of bioethanol.

Quality of protein isolate for monogastrics

The composition of essential amino acids in protein extracted from green biomass is very beneficial in relation to livestock needs; thus, the content of sulfur-containing amino acids is higher than for soya. The preliminary experiments produced a digestibility of 85 % from the protein fraction, and once the process is optimized a digestibility of +90 % for monogastrics is expected.

Potential high-value production from green biomass

From a value creation perspective only few documented evaluations exist of the potential of high-value production based on green biomass. The few existing evaluations point out that high-value products are very essential in order to achieve a healthy economy in the biorefinery process (Sanders 2015). It appears from the calculations that the value of protein production for feed is not, in itself, sufficient to cover the costs of running a biorefinery plant with the technology available at present. O'Keeffe et al. (2012) describes a process, in which feed protein is produced in combination with building insulation material. The examples provided by O'Keeffe et al. (2012) and Sanders do not include environmental and climate impacts, but consider the economic profitability. Thus, it is important to develop biorefinery technologies that utilize the full potential of biomass, either by means of synergies with e.g. biogas production (currently examined at Aarhus University) and/or by a concurrent extraction of specific ingredients. This requires a carefully designed process in order not to destroy the most valuable products when converting to less valuable products. This basic principle is called value creation by means of cascade utilization. The high-value potential of green biomass consists of several components. Among these the following should be emphasized: the highly purified protein fraction from green biomass may achieve the sufficient quality and nutritional value to be sold as baby food ingredients (e.g. as developed and up scaled for alfalfa). Metabolites, including molecules with medical and nutritional potential, may be purified and further developed. Last, but not least, a huge potential exists in the utilization of the considerable fraction consisting of hemicellulose polymers (C5 sugar polymers). C5 sugars may be processed (e.g. by means of enzymatic hydrolysis) to short, branched C5 oligomers. It has been demonstrated that these short sugar molecules, called dietary fibers, possess an interesting prebiotic activity. Prebiotic feed ingredients stimulate and strengthen the competitiveness in the healthy part of the intestinal flora and thus suppress the unhealthy and pathogenic part of it, thereby contributing to a reduced consumption of antibiotics. Therefore, feed ingredients seem the major and most natural market for prebiotic products.

Markets for green biomass

Feed protein market

This chapter describes the Danish consumption and import of protein. The chapter is mainly based on Bosselmann et al. (2015). In 2013 the total Danish feed consumption was approx. 40 million tonnes, of which 26 million tonnes were grass and green fodder produced in Denmark. The total feed import amounted to approx. 4.1 million tonnes and was primarily oil cakes from soya, rape seed and sunflowers as well as root crops and grains. The amount of crude protein summed to a total of 2.85 million tonnes, of which 1.05 million tonnes were imported (~37 %). Most of the imported crude protein comes from oil cakes, primarily soya cakes (incl. soy meal), which is the major single source of crude protein in Danish animal production.

Table 2. *Consumption of feed – both imported and produced in Denmark – in the season 2012/2013. Crude protein content stated in percentages is not per kg dry matter, but per kg imported feed. Consumption is stated in 1,000 tonnes*

	Feed weight 1,000 tonnes	**Of which crude protein 1,000 tonnes**			**Crude protein in feed, percent (calculated)**
Feed type	**Total**	**Total**	**Danish**	**Import**	
Total feed consumption, hereof:		2,850	1,799	1,051	
- Compound feed	-	1,808	782	1,026	-
- Roughage	-	1,042	1,017	25	-
Most important protein feed					
Soya cake	1,385	641	0	641	46.3 %
Sunflower cake	448	167	0	167	37.3 %
Rapeseed cake	506	165	79	86	32.6 %
Fishmeal, -silage and –waste	360	88	36	53	24.4 %
Grain feed					
Wheat	3,618	354	338	15	9.8 %
Barley	2,729	251	250	0	9.2 %
Roughage					
Grass & clover in rotation	14,546	611	611	0	4.2 %
Maize, silage	6,764	168	168	0	2.5 %[1]
Grass & clover outside rotation	3,170	108	108	0	3.4 %
Root crops and beet waste (industry)	2,538	54	29	25	2.1 %[1]

Source: Feed 1 table from Statistikbanken.dk

[1] *According to SEGES VFL (2013) the protein contents of maize silage and beet/root crops are 5.2 % and 6 – 10 %, respectively.*

Protein import

Denmark imports the protein-containing feed from a number of countries. Traditionally, soy meal – the most important protein source in Danish animal production – has been imported from Argentina and Brazil. Since 2011 the import of soy meal from Argentina has declined by 60 %, and according to the Department of Food and Resource Economics (IFRO) at the University of Copenhagen (2014), this is most likely due to negative media publicity and increasing consumer awareness of soya production in Argentina. This decline has been partly replaced by imports from the US, cf. Table 3. Likewise, the import from Germany has increased significantly, but this is actually re-export, which may be partly of Argentinian origin. The same is true for imports from the Netherlands (IFRO, 2012). In addition to soy meal, minor amounts of whole soya beans and toasted soya beans are imported and used for feed. Table 3 includes data for sunflower cake, which is mainly imported from Russia (50 %), Ukraine (23 %) and Germany (9 %). The import figures in Table 3 include soy meal and sunflower cake from conventional as well as organic production.

Table 3. *Danish import of protein crops used for feed. Based on the KN8Y table from Statistikbanken.dk*

Protein crop imports, 1,000 tonnes				
Soy meal	**2013**	**average '05 - '11**	**Sunflower cake**	**2013**
Argentina	493.3	1,234.5	Russia	178.8
Germany	340.8	84.5	Ukraine	85.2
Brazil	241.9	237.8	Germany	33.5
USA	232.8	18.5	Estonia	18.8
Netherlands	88.4	76.1	Argentina	14.0
Canada	23.79	3.1	Lithuania	11.6
Others	43.4	35.4	Others	21.0
Total	1,689.9	1,464.4	Total	362.90

Source: Statistikbanken.dk/KN8Y.

Import of organic protein

Qualitative data regarding import and use of various organic feeds has been provided by the Danish AgriFish Agency (Organic Inspection) as well as major Danish feed producers, while Statistics Denmark provided specific information about the countries from which Denmark imports protein feeds. Attention should be paid to the fact that it is often the harbor of embarkment that appears in the statistics and not the country of origin. In 2013 the total value of the Danish import of organic feeds (except unground grains) constituted 226 million DKK, which is approx. four times the import of 2009 (Table 4). More than half of the organic feed import comes from Asia (123 million DKK), primarily soy meal from China. This also explains the significant growth in total imports as the import of organic feed from Asia was only marginal until 2012. Chinese soya production is based on non-GMO types, which is required in order to achieve organic certification. Imported organic soya has been certified by EcoCert, of French origin, but is used worldwide, especially in Europe. Denmark also imports organic soy meal from Kazakhstan (since 2012), certified by BIOZOO which was previously involved in certain cases relating to bribery and import of soya and grains that claimed to be organically certified but were actually conventionally produced. According to the international trade statistics the total import of soy meal from China and Kazakhstan constituted 107 million DKK (22,500 tonnes) in 2013. This probably constitutes the major part of total imports of organic feed from Asia (cf. Table 4) as Denmark does not import significant amounts of feeds from other Asian countries.

Table 4. *Import of organic feedstuffs, except unground grains, in 2013.*

Feed imports, 1,000 DKK	**2009**	**2013**
ASIA TOTAL	0	122,617
EUROPE TOTAL	55,409	103,814
Germany	12,072	40,526
The Netherlands	5,576	35,551
Italy	31,490	22,952
Total, 1,000 DKK	55,409	226,431

Source: Statistikbanken.dk/OEKO6.

Protein produced in Denmark

In the recent years there has been an increased focus on the declining protein content of Danish feed grains and, consequently, an expected increased soya import to compensate for the lower protein content. The Danish national field experiments have demonstrated the declining protein content; during the last two decades the protein content of Danish wheat has declined from 11 % to 8.5 % (Møller and Sloth, 2014).

It is, however, not possible to substantiate – using data for protein import and slaughter pig production – whether or not this is actually the case. Figure 3 shows the Danish import of raw protein in oil cakes from soya, rapeseed and sunflower compared to the production of slaughter pigs for export and slaughter in Denmark.

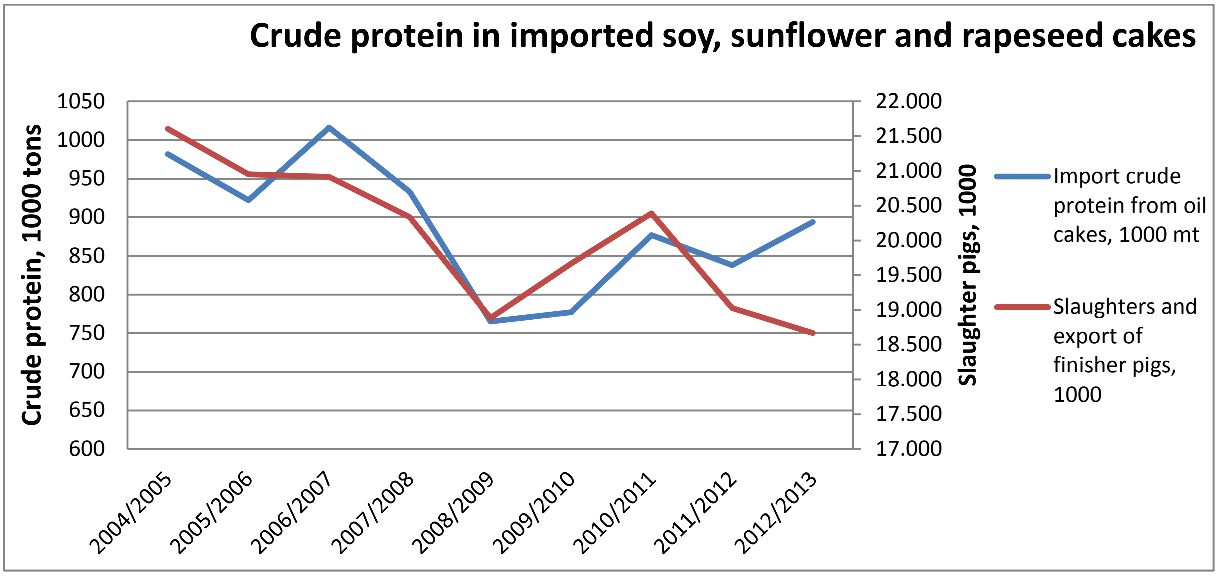

Figure 3.

As it appears from Figure 3, the development in the import of crude protein from oil cake corresponds fairly to the development in slaughter pig production which is mainly affected by market prices and demand. Soya imports may have increased as a result of the declining protein content in Danish feed grains, but it is difficult to trace a direct effect from the data. It is worth noticing that soy meal imports have decreased gradually during the last seven years; in absolute figures as well as relative to other oil cake types. According to import statistics the import of soy meal has been replaced by import of especially sunflower cake. Considering the import share of raw protein from oil cake, sunflower cake import has increased from 6 % in 2005 to 19 % in 2013, whereas soy meal imports decreased from 86 % to 72 %.

Financial potential

Figure 4 provides an overview of the share of different feeds in raw protein consumption in Danish agriculture. About half of the rapeseed cakes are produced in Denmark and the rest of the oil cakes are imported. The organic share of this import is 6.1 % for rapeseed cake and 1.7 % and 1.9 % for sunflower cake and soya cake, respectively. Grains for compound feed, wheat and barley in particular, are mainly produced in Denmark (93 %). About 3 % of the farmland used for grain production is organic, but the share of organic grains for feed is supposedly higher, as for instance 10 % of dairy production is organic, and grains constitute a significant part of the feed for organic dairy cattle. Grass and green fodder are almost solely produced in Denmark and about 18 % of the grassland area is organic.

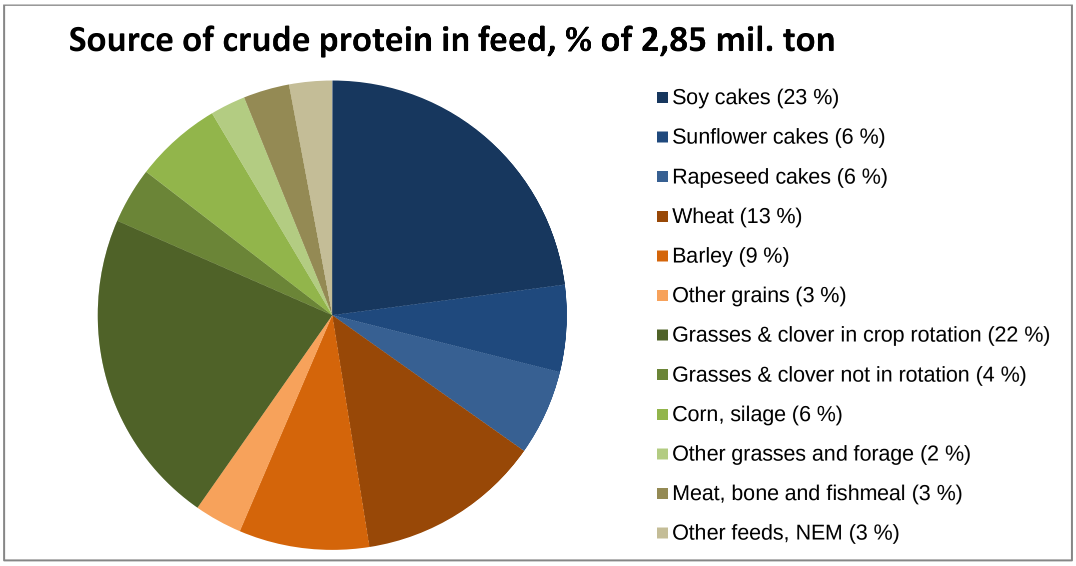

Figure 4. *The share of different feeds in crude protein consumption in 2012/13. The share of each feed source is indicated in percentages (in brackets).*
Source: Statistikbanken/OEKO6.

Oil cake, soya in particular, constitutes the major part of the imported crude protein (Figure 5). The majority of the imported protein is soy meal from Argentina, Brazil and USA, and it is used mainly in pig production but also in other types of animal production. Likewise, sunflower and rapeseed cakes are used for a variety of production purposes, whereas flesh meal & bone meal and fishmeal is mainly used as mink fodder.

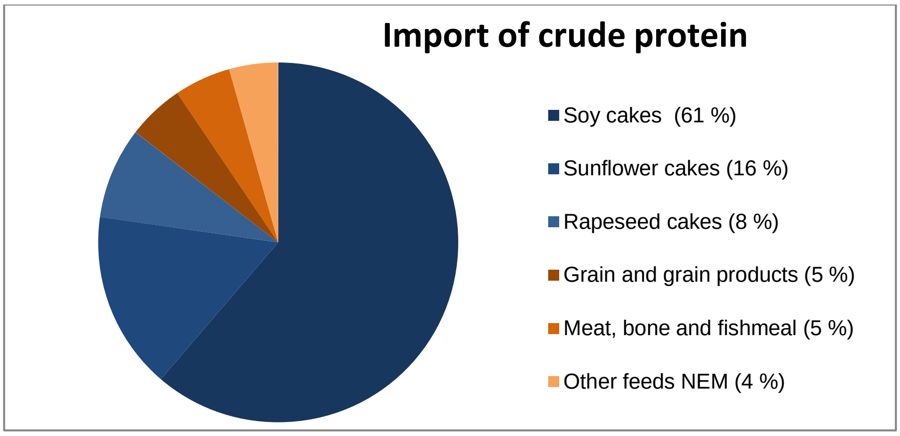

Figure 5. *The share of different feeds in crude protein imports in 2012/13. The share of each feed source is indicated in percentages (in brackets).*
Source: Statistikbanken/OEKO6.

Experiences in relation to commercialization of protein products from green biomass

As appears from the above there is a huge Danish market for proteins, and the production of protein isolate from grass and legumes is not a new idea. The process has been known for more than a century, and the possibility of extracting nutritious protein from green biomasses and using it as a supplement for human nutrition or animal feed has been suggested several times (cf. e.g. Houseman & Connell, 1976 and Pirie NW, 1987). However, in spite of several initiatives, an actual commercialization has never occurred. This may be due to the fact that globalization, inexpensive transportation, trade agreements and a focus on high grain yields in the EU have made the present soya import practice a more favourable solution. However, various reasons suggest (all mentioned previously in the present report) that a more sustainable alternative to soya imports exists.

Regarding commercial production of protein isolate from green biomass only one active producer is known to the authors. The French feed producer Désialis, who mainly sells alfalfa hay, also has a niche production of protein isolate from alfalfa, which is primarily used in feeds for egg layers and pets. According to Désialis the concentrate has a high protein content (>50 %) and it is rich in vitamins, iron and omega-3 fatty acids. In many ways Désialis's production and marketing illustrates the opportunities of an actual commercialization of protein isolate from green biomasses (http://www.desialis.com/en/our-products/cae-concentrated-alfalfa-extract). Cf. Ecker et al. (2012) and Houseman & Connell (1976).

Non-marketed impacts of an increased use of green biomasses

Analyzing environmental impacts a distinction is usually made between direct and indirect impacts. The direct impacts of producing green biomass in Denmark are related to changes in land use and the environmental consequences following from these changes. The most important of these environmental consequences are changes in nitrogen leaching, and reductions in the emissions of greenhouse gasses and in the use of pesticides. If the Danish production of protein rich feed is increased to the extent that protein imports are affected significantly, the land use changes in Denmark may impact other countries, e.g. by inducing changes in land use there. Prior to increasing the Danish production of green biomass for feed protein it is therefore important to analyze if and how the substitution of soya feed for green biomass produced in Denmark entails consequences abroad, thereby allowing potential detrimental effects to be identified.

Direct environmental impact when converting to green biomass production

Permanent soil cover, which can be achieved by growing green biomasses, has positive environmental effects; it extends the growing season and it allows for the establishment of a permanent root system. Both of these factors contribute to increasing the efficiency of nutrient use (Jørgensen et al., 2013), which has been shown to have an even larger effect in terms of minimizing nutrient loss than the amount of fertilizer applied has. Eriksen et al. (2014) has compiled a catalogue of measures which may be used to mitigate nitrogen leaching in Denmark, and in this context it is estimated that the conversion of land from conventional farming to continuous grass production entails a reduction in nitrogen leaching from the root-zone of 50 kg N/ha. The estimate is based on a model calculated average leaching from conventionally farmed areas of 62 kg N/ha (Børgesen et al., 2013) and an average leaching from areas with continuous grass production of 12 kg N/ha. In Eriksen et al. (2014) no distinction is made between effects on loamy and sandy soils. Results from Andersen et al. (2012), however, suggest that the effect varies across soil types, and the reduction in nitrogen leaching associated with converting from conventional agriculture to permanent grass is estimated to be 34 kg N/ha for loamy soils and 61 kg N/ha for sandy soils.

Conversion of land from conventional production to rotational grass production is estimated to entail a reduction in nitrogen leaching of approx. 20 kg N/ha. The estimate is based on a model calculated estimate of the average leaching from conventional farmland of approx. 62 kg N/ha (Børgesen et al., 2013) as well as a model calculated estimate of the average leaching from grass and clover fields in rotation of approx. 42.5 kg N/ha in the period 2005 – 2011 (Danish Environmental Protection Agency, 2015). Assuming that the relative difference in effects across soil types in this context is similar to the one identified in Andersen et al. (2012), the soil type specific impacts can be estimated to 14 kh N/ha for loamy soils and 26 kg N/ha for sandy soils.. Standard practice within present agriculture is to convert every 2-3 years when producing grass. This practice generally entails significant leaching from the subsequent crop. For green biomass production to be desirable seen from a welfare economic point of view it is important to account for the potential environmental effects. Hence, in order to reduce nitrogen leaching it is important to convert at longer intervals than what is common practice now and/or to effectively reestablish grass cover after conversion. In on-going experiments DCA/AU have fertilized grassland using up to 500 kg N/ha, and subsequently they have measured the nitrate concentrations in the water flowing though the soil. The measurements have revealed a slightly lower nitrate concentration compared to the one found in connection with non-fertilized clover grass; the difference, however, was not significant. In relation to producing biomass for biorefineries or biogas plants it is important to have a continuous production, and it is reasonable to fertilize the fields. Consequently the calculations in section 3 are based on the assumption that the grassland areas are converted at 5-7 year intervals and that they are cut three times a year. Moreover, it is assumed that grass is established immediately after conversion in the spring barley crop, which is cultivated following the conversion.

Previous reports (e.g. Eriksen et al., 2014) conclude that leaching from perennial energy crops will be 10-30 kg N/ha when calculated across the entire rotation period. This level of leaching is assumed also to be applicable for the management systems described above including either non-fertilized clover grass or fertilized grass. In terms of rotation period, it is estimated that rotation periods of up to 5-7 years can be implemented without leading to significant reductions in production (Eriksen et al., 2004). If an average crop rotation is converted to perennial energy crops, findings from Eriksen et al. (2014) indicate that nitrate leaching is reduced by 34 kg N/ha for loamy soils and 51 kg N/ha for sandy soils . It is assumed that this nitrogen leaching reduction potential can be extended to an optimized production of biomass with long rotation periods. However, this cannot be verified at present and it should be analyzed further in the future.

In addition to the nitrogen impact, the transition from annual crops to perennial crops is also expected to lead to an increase in the carbon stock in the soil; the effect, however, is currently insufficiently quantified. In Eriksen et al. (2014) the soil carbon effect of converting from conventional crop rotation to permanent grass is estimated to 1.8 t CO_2/ha/year. The increase will continue over a longer period of time (between 20 – 40 years) until a new equilibrium is established. Apart from the soil carbon effect, the change in crop rotation also affect the carbon balance through changes in the emissions of nitrous oxide, which are caused by differences in the application of nitrogen across different rotations. As an example, the increased use of nitrogen associated with a conversion from crop rotation to intensive grassland in rotation will result in an increase in nitrous oxide emissions of 1-1.3 t CO_2 equivalents/ha. Finally, a conversion from conventional crop rotation to grass is likely to entail a decrease in the use of pesticides; hence, pesticide use for grass (treatment index of 0.04 according to the biocide statistics) is very low compared to pesticide use in grain crops (treatment index of 2.7-4.3 (spring crops/winter crops).

Indirect environmental impact when converting to green biomass production

Globally, we witness a continuous expansion of the agricultural farmland as a result of the increasing demand for biomass for food, including animal feed and for bioenergy purposes. When forests or savannahs are used for cultivation, an emission of CO_2 from the existing biomass – above or below the soil – takes place and in many cases the biodiversity will be significantly reduced.

It is estimated that the importance of such land use change corresponds to approx. 12 % of the world's total greenhouse gas emissions, to which the agricultural sector (not including land use change) contributes approx. 14 % by comparison. This is called the indirect land use change (ilUC) and its contribution needs to be added to the calculated direct emission of greenhouse gasses.

Audsley et al. (2009) calculated that each hectare of included agricultural farmland entails an indirect CO_2 emission of 1.43 tonnes CO_2 as a consequence of the increased pressure on the land resource. This calculation presupposes an increased carbon emission, as a consequence of land use change, of 8.5 Gt CO_2/year, of which 58 % is caused by agricultural production and the rest by other circumstances such as e.g. infrastructure. Roughly speaking, this emission is distributed to the world's agricultural area 457 Mha).

Searchinger et al. (2008) estimated that the required inclusion of additional farmland for bioenergy production in the USA would imply an indirect CO_2 emission of 600 g per m^2 as a consequence of global land use change. This corresponds to 6 t CO_2/ha and is thus considerably higher than the estimate by Audsley et al.

In connection with the Commission's efforts to prepare the bioenergy policy, the Commission asked IFPRI (The International Food Policy Research Institute) to assess the indirect land use change as a consequence of increased demand for biomass for bioenergy (the background report ”Assessing the Land Use Change Consequences of European Biofuel Policies”). The estimates they came up with were close to the estimates of Searchinger et al. (2008).

Just like an increased biomass demand for energy purposes will cause land use changes, a conversion of land to green biomass production will do the same. In relation to the utilization of green protein it will be of vital importance to iLUC (indirect land use change) whether a higher or lower yield is achieved by means of this method. As appears from the above, a higher total yield is expected when growing grass fertilized by nitrogen rather than cereals, which will help reduce the indirect land use change caused by the Danish animal production.

In the example illustrating how protein for monogastrics is extracted from high-yielding grass fertilized by nitrogen and the rest is used for cattle feed (Table 1) it is estimated that this can generally be accomplished without expanding the crop area or reducing other crops in Denmark. This means that the indirect impact is solely an effect of reduced land use outside Denmark corresponding to the extra production of 600,000 tonnes soy meal achieved and the CO_2 emission related to cultivation and transport to Denmark.

Cultivation, processing and transportation to Denmark emit approx. 520 kg CO_2 per ton soy meal (Mogensen et al., 2015). To this should be added GHG emissions resulting from global land use change and inclusion of savannahs and forests for cultivation purposes. As mentioned previously, these estimates are uncertain, but using the results from Audsley et al. (2009) and Searchinger et al. (2008) as a starting point they range from 140 to 600 g CO_2/m^2. The production of 1 kg soy meal requires 3.5 m^2 (adjusted for the co-produced amount of oil) (Dalgaard et al., 2008). This means that indirect CO_2 emissions range from 490 kg to 2.1 ton CO_2 per ton soy meal produced. All in all, an increased production of 600,000 tonnes soy meal ‘equivalents’ will reduce the CO_2 emission outside of Denmark by 0.6 – 1.6 million tonnes.

Employment effects

Calculations and assessments of employment impact in relation to the application of biomass for e.g. energy purposes or bio refining mainly included “yellow biomasses” or a mixture of biomasses, while only few assessments were made of the employment impact when applying green biomass. Copenhagen Economics recently published the report “Geographical employment potentials within bioeconomy”. To a significant extent the report is based on the results from the ”+10 million tonnes plan”. CE estimates that a complete implementation of bio economy will create a total, permanent employment effect in the order of 23,700 full-time equivalents. Of these almost 80 %, corresponding to 18,500 full-time equivalents, will be found in rural districts.

The report does not provide an estimate of the employment impact in relation to the application of green biomass for protein production, but however, it states that utilization of green biomass will have a significant, positive effect on employment.

The two examples below illustrate the calculated employment impact in relation to specific examples which may partly be compared to the application of grass for bio refining purposes.

Utilization of 325,000 tonnes biomass from permanent grasslands for biogas

As is the case with straw, grass needs pretreatment by means of an extruder if it is to be used as feedstock in a biogas plant using slurry. In a report Hermansen et al. (2014) presuppose an annual, realizable biomass potential of 325,000 tonnes from grass, corresponding to a permanent grassland area of 50,000 ha. The report states that treatment of the 325,000 tonnes of additional biomass will require 13 plants.

The direct employment impact is estimated to 92 full-time jobs per year, while indirect employment effects constitute 14 full-time jobs.

Utilization of 1.6 million tonnes of catch crops for biogas

Unlike relatively dry grass, biomass harvested from catch crops may be immediately applied in the biogas plant without pretreatment. The report by Hermansen et al. (2014) estimates that there is a potential of 1.6 million tonnes of catch crops, corresponding to 650,000 tonnes dry matter or 430,000 ha of catch crops. However, this requires optimized cultivation.

The calculated effect on the gross factor income (the BFI effect) is 53 million DKK per year, primarily related to biomass harvesting, and direct and indirect employment impacts amount to approx. 800 full-time jobs, of these more than 700 in primary production. If labour-saving technologies are implemented the employment impact is reduced to 444 full-time jobs.

In the report ”Analysis of the regulatory and subsidy landscape governing biomass use” (COWI, February 2015) COWI estimates that an application of green biomass for protein feed will create two permanent (1.99) jobs for each million DKK that is invested in this trade.

In relation to the example described below of a central biorefinery this corresponds to 1,000 jobs when investing in such a refinery (cf. Table 6).

Challenges – storing and logistics

Costs for handling, storing and transportation constitute a significant part of the total costs in green biomass production. Logistics in relation to handling and utilization of green biomasses may be divided into four logistic levels: field level, between fields, between sectors and interregional. Regional logistics are important for yellow biomass such as e.g. wood chips and pellets, whereas it is limited for green biomass as it contains a lot of water. In order to optimize logistics it may thus be necessary to reduce the amount of transported water. It is a common property for green biomass that it is only available in our part of the world for parts of the year. During a long period from late autumn until spring it is not possible to harvest fresh biomass. Therefore, it may be necessary to store biomass or biomass products for a long period in order to ensure a continuous production or product delivery.

When green biomass is used for high-value products and energy, it is important for the producer to have a continuous biomass supply of a predictable quality. This is important for the production in itself, but a continuous supply may also help reduce the costs at the refinery for e.g. storage capacity and reactor tanks. Green biomass has high water content and is not easily stored after harvest. In order to store biomasses they must either be dried or stored in an anaerobic atmosphere in order to avoid reduced quality. Drying is expensive unless the biomass is dried in the field by the sun and the wind. Oxidation is reduced by ensiling, packing and gastight storage or by performing a treatment of the biomass that preserves products or intermediate products in order for these to maintain their value. Further, storage loss also depends on factors such as the sugar content of the biomass, temperature and pH.

Considerable experience exists within harvest and storage of green biomass for feed. Generally, handling should involve as few operations as possible and the biomass should be stored as soon as possible after harvest and drying, if needed. The optimum harvest time depends on the application purpose of the biomass. For instance, the protein content of grass changes through the season. As it is harvested 3-4 times in order to achieve an optimum biomass production, the quality of the individual cuts may differ.

A number of tools are available for the optimization of logistics, especially route optimization between different destinations. In addition, universities have developed programmes to be used in the optimization of harvest and gathering of biomass from individual fields, and efforts are accomplished to make information about the individual processes available online.

Challenges – business economics

Chapter 2.1 describes the potential of green biomass production, while chapter 2.2 describes the potentials of bio refining of green biomass. This chapter assesses the economic potentials of “green protein” production and other high-value products by bio refining of green biomass. Table 5 shows the contribution margin estimates for grass production in the form of perennial grass in rotation and optimized cultivation, respectively (cf. chapter 2.1).

As the optimized cultivation method is not practiced in Denmark at present, this estimate is somewhat uncertain, more so than the estimate for standard fertilized grass in rotation. The estimates used to calculate the contribution margins are based on the crop type "permanent grass for cutting" laid out in the budget estimates for 2014 (farmtalonline.dk). However, adjustments have been made in relation to yields, N, P and K input, number of cuts and machinery costs in order to reflect the various production types. As it appears, the cultivation costs range from 694 DKK/t DM for optimized green biomass in loamy soils to 874 DKK/t DM for perennial grasses in rotation in irrigated sandy soils.

In relation to the production and sale of a fiber fraction and a protein fraction, as described in chapter 2.2, the prices indicated will ensure a positive contribution margin II in all cases. This amount should be able to cover the costs for bio refining.

Table 5. *Productivity and gross margin estimates for different cultivation systems for sandy/irrigated sandy/loamy*[*]

	Grass in rotation (Standard norm) (350 kg N/ha)	**Optimized green biomass (425 kg N/ha)**
PRODUCTIVITY		
Dry matter (ton)	9/10/10	13/14/14
Feed units fiber fraction (FU)	4644/5080/5080	6628/7257/7257
Feed units protein (FU)	2179/2383/2383	3109/3404/3404
GROSS MARGIN		
Net income[**] DKK/ha	11087/12184/12184	15839/17406/17406
Seed costs, N, P, K (DKK/ha)	3817/3817/3697	6183/6183/6183
Gross margin I, DKK/ha	7270/8357/8487	9657/11223/11223
Machine and labour costs (DKK/ha)	3474/4716/3501	3474/4716/3501
Cultivation costs per ton dry matter (DKK/t DM)[***]	821/874/737	761/781/694
Gross margin II (DKK/ha)	3796/3651/4986	6182/6508/7722

[*] The three levels in each cell refer to the levels of sandy/irrigated sandy/loamy.

[**] Price of 1.18 kg/FU fiber fraction; 2.54 DKK/FU protein

[***] Costs do not include ensiling.

Table 6 shows the estimated profit and loss account for two biorefinery ”examples”, a central refinery and a decentralized refinery placed on loamy soil. This allows a comparison of the two types of bio refineries.

Table 6. *Profit and loss account for bio refining of green biomass on loamy soil in a central and a decentralized plant.*

Bio refining	**Central plant**	**Decentralized plant**
Protein isolate		13,410,000
Upgraded protein isolate	170,992,400	
Grass fibres	97,758,900	13,983,650
Income, DKK	268.751.300	27,393,650
Cultivation	104.871.429	13,982,857
Transport	27,937,500	
Costs I,DKK	132,808,929	13,982,857
Gross margin I, DKK	135,942,371	13,410,793
Energy consumption, DKK	44,700,000	1,788,000
Salaries, DKK	5,587,500	745,000
Maintenance, DKK	20,860,000	745,000
Costs II, DKK	71,147,500	3,278,000
Gross margin II, DKK	64,794,871	10,132,793
Interests and depreciation, DKK per year	41,846,509	1,435,500
Refinery costs per ton DM	940	236
Total costs, DKK	245,802,938	18,696,357
Result of primary operation, DKK	22,948,362	8,697,293
Internal rate of interest, %	10.84	67.98

The above calculations are based mainly on Ambye-Jensen and Adamsen (2015b) as well as the authors' own calculations in relation to this report. Data are from project material describing the two biorefinery examples prepared in connection with the BIOVALUE project and the establishing of AU BIOBASE. The central refinery example is based on a plant processing 150,000 tonnes of dry matter from green biomass each year. It is presupposed that the plant is built in connection with a biogas plant, and the products for sale will be upgraded protein isolate and grass fiber. The decentralized plant is also built in connection with a biogas plant and will treat 20,000 tonnes of dry matter from green biomass each year. Protein isolate and grass fibers will be the products for sale.

As appears from Table 6 both plant types will yield a positive economic result; however, if we consider the return on the invested capital then the decentralized plant is the best solution. Please cf. Ambye-Jensen and Adamsen (2015b) for a detailed description of the financial results. Please note that the above results differ from the results described by Ambye-Jensen and Adamsen (2015). This is due to the fact that the estimated raw material costs are significantly higher than in the present report. As raw material costs constitute about half of the total costs this will naturally affect the total financial result.

Challenges – regulatory barriers

As described above a transition to domestic production of green biomass may entail a series of environmental benefits. However, these benefits are of a non-market character, and therefore they represent no direct economic value for the individual farmer. Consequently, farmers have no incentive to consider these benefits when making decisions on land use. In Denmark, the leaching of nitrogen from agriculture has primarily been regulated via a standard norm system, which limits the application of nitrogen to a level 10 % below the economically optimal level. Recent results show that the actual nitrogen application rate under the current norm system is 16 % below the economically optimal application rate (DØRS 2015, page 51). This norm based model implies that the current regulation of N is based on restrictions in production. An alternative, and more desirable approach, would be to target the regulation directly at the leaching of nitrogen, as this represents the environmental effect that the regulation is intended to address. Hence, it is the leaching – not the application - of nitrogen that needs to be regulated in order to achieve an improved water quality in freshwater as well as marine ecosystems. The way that nitrogen use currently is regulated provides no incentives for farmers to convert to crops with reduced nitrogen leaching. Hence, current regulation does not reflect the environmental benefits associated with converting from grain based production to the production of green biomass. There are considerable practical challenges associated with devising a regulatory system based on emissions to the aquatic environment as it is not possible to measure actual emissions from individual farms. However, other models have been suggested to regulate nitrogen in a more economic and optimal way, see e.g. the report from the Danish Economic Councils 2015 (DØRS, 2015).

According to EU regulation grass must be converted every 5 years as a minimum in order to qualify for the EU basic payment to agricultural production in rotation. If this requirement is not met the area is converted to permanent grassland. A significant share of total leaching from grasslands is related to conversion; from an environmental perspective it is therefore relevant to adopt longer conversion intervals. As described in above, it may be possible to extend the rotation period for grass production beyond the 2-3 years commonly practiced in Denmark without incurring significant production losses. However, due to current regulation, extending the rotation period beyond 5 years is problematic, as this entails a significant reduction in the EU subsidy received by farmers.

Increasing the N standard norm for grass for bio refining purposes also involves regulatory challenges, as it may be difficult to control whether the increased amount of nitrogen is actually applied to the fields producing green biomass where the level of nitrogen leaching is low. Hence there is a risk that the additional nitrogen will end up being applied on other crops with high nitrogen loss.

Summary of background information

The major part of the Danish farmland is used for grain production. Grains are relatively simple to cultivate, harvest, transport, store and process, but they are not very efficient when it comes to utilizing sunlight and fertilizers. Grass and other green crops have much longer growth periods than grain crops and thus make better use of both sunlight and fertilizers. Under Danish conditions, green crops are able to produce significantly higher yields than grains. In addition to this, green crops are usually associated with lower levels of nitrate leaching and they require almost no pesticides. The majority of grains produced in Denmark are used for pig feed, but the protein content of the grain is too low to cover the nutritional requirements of pigs, and therefore it is necessary to supplement with imported soya protein. The soya is primarily imported from South America, where the Danish import influences land use and, consequently, underpins the environmental problems associated with soya production. With reference to the potential positive effects of green crops compared to grain crops, combined with the negative effects associated with importing soya, it is relevant to examine if it is possible to produce protein feed based on green biomasses grown in Denmark. The main perspective is to extract the water-soluble protein, preserve or dry it, thereby creating a digestible protein which can be used instead of soya. The remaining fraction can be used as cattle feed, or as input to the production of bioenergy and bio-based materials. Such use of green biomass would be in line with the visions of replacing fossil raw materials with bio-based raw materials. The examples in this report illustrate how the high productivity of grass facilitates the production of protein of a quality comparable to that of soy meal while maintaining the production of cattle feed at its current level.

The market for protein produced for feed is huge, but it is a very price-sensitive market. Hence, competitive technologies will be a prerequisite for realizing the potentials of green biomass as an input to feed production.

Protein for feed is not the only potential of green biomass. Green biomasses also have a significant potential in relation the production of feed and food ingredients, as well as medical and nutritional products. The markets for these products are less price-sensitive, but the development of both markets and products are more uncertain for these alternative uses of green biomass.

Some challenges remain to be solved before the potentials of green biomasses can be realized. The primary challenge is to devise ways of extracting protein from the green biomass that are competitive to soya protein both in terms of price and quality. Another challenge is how to convert the residual produce into a marketable product. Finally, several challenges exist in relation to the harvest, transportation, storing and processing of green biomasses. Especially the considerable water content of green biomass constitutes a challenge.

Farm accounts reveal that grass in rotation, when adhering to current cultivation practices, is often not competitive compared to rotations involving ordinary crops. Hence, on many fields the gross margin of ordinary crop rotations exceeds that of grass in rotation. If grass cultivation practices are optimized, however, grass rotations may potentially become competitive. At present optimized grass cultivation systems have only been examined in research projects, and trials conducted under more real world situations are required before final conclusions can be made.

When converting from grain production in rotation to grass in short rotation, the leaching of nitrogen to surface water is estimated to be reduced by approx. 20 kg N/ha. If the grass production is optimized in an extended rotation, it is estimated that a significantly higher reduction in nitrogen leaching can be obtained. More specifically, the leaching is expected to be reduced by 50 kg N/ha, corresponding to the reductions previously measured for permanent grassland. Preliminary research results support this, but it is necessary to continue the monitoring of the experiments for a number of years in order to be able to validate the estimates of the impact which conversion to optimized production of green biomass in rotation have on the aquatic environment. The effect on climate gas emissions is uncertain.

Several regulatory barriers preventing the realization of the potential benefits associated with the production of green biomass are identified. Specific attention is directed at the current standard norm regulation which is shown to provide no incentive for farmers to convert to crops that reduce leaching to the aquatic environment. Moreover, the EU subsidy requirement that grasslands need to be converted at intervals no longer than 5 years is shown to discourage the cultivation of grass in extended rotation.

Illustration of production and environmental potentials of green biomasses

In order to improve the knowledge regarding the operational and environmental economic consequences of converting from grain production in rotation to grass in rotation an analysis was conducted for 12 actual areas surrounding the Limfjord. Each of the areas has been designated in order to represent an area able to feed a small decentralized biorefinery plant. The Dutch mobile plant (Sanders, 2015) with a capacity of 500 ha green biomass was used as inspiration. This plant is significantly smaller than the decentralized plants previously analyzed in Denmark. As operational economics, nitrogen and climate impacts vary according to soil type and hydrology, the areas have been chosen in order to represent the different possible combinations of soil type (loamy, sandy), retention (high, medium, low) and highland/lowland (Figure 6). Thus, the areas have been selected to illustrate the variation in the region.

The analysis is intended to illustrate differences in terms of gross margins and environmental impacts between current production and various scenarios for conversion to green biomass production. The gross margins for the grass production scenarios have been calculated based on the assumptions listed in chapter 2.8, and the gross margin for the present crop production in the area has been calculated based on farm economic accounts made available by the agricultural research and advisory institution SEGES (Farmtalonline,2015). The nitrogen impact is calculated based on the effects stated in chapter 2.5, and the value of the impact is assessed based on the shadow price approach (marginal costs taken from DØRS, 2015; Hasler et al., 2015). Using this approach, the value of conversion is expressed in the form of a reduction in the costs associated with achieving the environmental goals set for the aquatic environment in the Limfjord. The climate impact has been estimated based on the effects stated in chapter 2.5, and the value of the impact is assessed based on the marginal CO_2 reduction cost estimated for the Danish sectors not covered by the EU quota trading scheme (KEBMIN, 2013). This means that the calculations in Table 7 only include environmental effects related to the national nitrogen targets set by Danish policy and the climate impacts included in Danish climate gas accounts. Any potential derived effects in the form of iLUC are therefore not included in the calculations.

Table 7. *Economic consequences in terms of gross margin, nitrogen and climate impact of conversion to standard norm fertilized grass for bio refining in short rotation and optimized grass production in extended rotation. Variations (brackets) cover differences in soil type and retention conditions.*

DKK/ha	**Standard fertilized grass – short rotation**	**Optimally fertilized grass – extended rotation**
Change in gross margin Average (min:max)	**27** (-1653:1309)	**2637** (1084:3828)
Change in nitrogen value Average (min:max)	**547** (2:1145)	**1128** (4:2247)
Change in climate value Average (min:max)	**723** (445:838)	**419** (165:532)
Change in economic value (biomass, aquatic environment and climate) Average (min:max)	**1296** (-537:2904)	**4184** (2346:6288)

The calculations presented in Table 7 show that there are significant differences between the operational economic potential and the environmental potential associated with converting to grass production in the 12 locations encompassed by this analysis. Seen from the perspective of the individual farmer, the incentive to convert to standard fertilized grass in rotation is negligible; the average increase in profit is 27 DKK/ha. Including both environmental (nitrogen) and climate benefits, the increase in economic returns following conversion is estimated to be 1296 DKK/ha (including both private and social impacts). Further, the calculations demonstrate that there seems to be a net economic profit associated with converting to optimized grass production for biorefinery purposes in the 12 areas, and the estimated profit is seen to increases when environmental and climate benefits are included. The assessment of the climate effects associated with the conversion from grain to grass production is subject to significant uncertainty. Hence, the results of the assessment very much depend on the underlying assumptions in relation to the areas subjected to conversion and the economic value of CO_2 reductions. In the present report it is presupposed that the areas to be converted presently are used for production of grain crops, and the value of the climate impacts is assessed based on the estimated alternative costs associated with reducing CO_2 – emissions within the sectors not covered by the EU quota scheme.

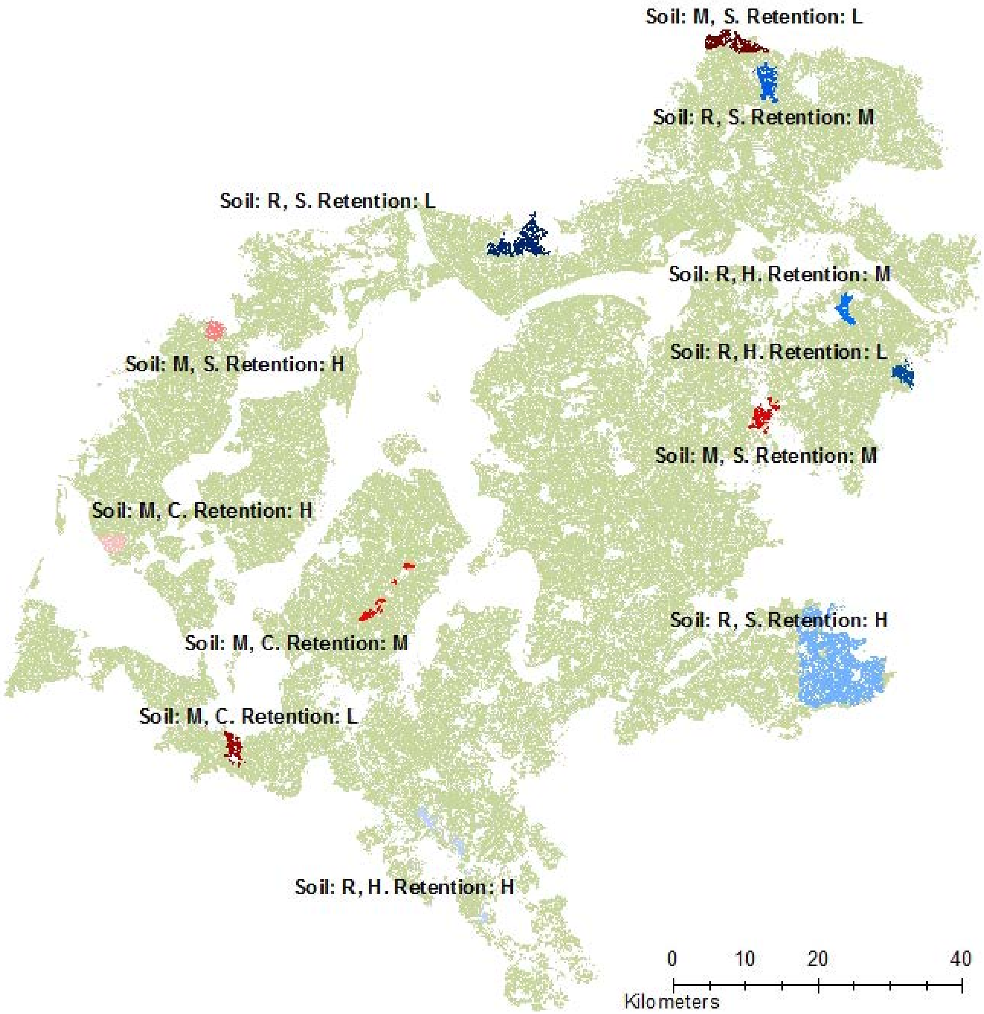

Figure 6. *Selected areas used to illustrate calculations of production, nitrogen and climate impacts. Soil: M/R = Minerogenic soils / Riparian hydromorphic soils; Soil: S/C/H = Sand / Clay / Humus soils; Retention class L/M/H = Low 20-60, Medium 60-80, High 80-100*

Conclusions and focus areas

Several stakeholders have expressed an interest in replacing the considerable import of proteins with protein produced in Denmark; the interest is partly motivated by climate considerations and concern over the negative environmental impacts which import of proteins entail in the producing countries. . Several research projects focus on finding new sources of green protein sources which can be produced in Denmark with a low environmental impact. However, a number of challenges remain to be overcome before green proteins are able to replace South American soya. The major challenge is related to technological developments within bio refining of biomasses of different origin to high-protein feeds optimized for monogastrics and ruminants, respectively. Provided that this technology is developed it is expected that the production of protein from new sources can be optimized, also in relation to environment and climate. The extent of this potential new protein production will depend on the development of new production systems, the extent to which new protein sources will replace or supplement existing sources, and, last but not least, the price and quality of the protein product compared to existing protein sources. The agricultural industry and feed producers are subject to global competition, and in addition to regulation and consumer demands, price is an important determinant of which type of protein feed that is used in animal production. It has been established that there is a potential for developing and producing high-value products from green biomass, but only few examples of commercialization of such products exist.

So far, grass production has been optimized towards the production of feed for cattle, but there is a potential in developing cultivation systems and grass types optimized for biomass production. The protein content of grasses is significantly lower than that of clover, but at yield rates of more than 20 tonnes of dry matter per ha, as harvested for festulolium in research trials, even a moderate improvement of the protein content will entail a considerable effect on total protein yield. Conversion of traditional annual crop rotations to perennial crops, or optimization of annual cultivation systems using e.g. double cropping, may also lead to significant reductions in environmental impacts. Further verification of the environmental effects following a conversion from grain rotation to the production of grass for bio refining purposes is however required. In addition to this, there is a need for increased knowledge in relation to optimizing protein composition and availability of feeds, anti-nutritional factors etc.. Finally, new promising processing tools (precision processing) may be used in the processing of grasses for bio refining purposes.

The present nitrogen regulation does not provide an incentive for farmers to adopt cultivation practices that support full realization of the environmental potential of green biomass. Similarly regulatory requirements limiting the conversion intervals for grass to a maximum of five years may also constitute a barrier for optimizing grass production. Considering the challenges regarding the aquatic environment and the climate goals, it is important to ensure that bio economy initiatives are designed in conjunction with other policies affecting agricultural land use. The analyses presented in the report suggest that an optimized production of biomass may contribute to the attainment of several important environmental goals. However, the analyses also indicate that the choice of cultivation system has an important bearing on the actual end-effects, and that a significant geographical variation exists in relation to environmental impact. It is thus of major importance to consider these aspects in the design of regulatory instruments.

Research shows that the Netherlands has devoted significant efforts into the development of a bio economy. Accordingly it may be advantageous for Denmark to engage in cooperation with relevant Dutch partners. For instance, the Netherlands has experience in the development and testing of decentralized plants; experiences that Denmark may learn from in order to achieve practice-oriented experiences within logistics, processes and product development.

Both the Netherlands and Denmark are highly developed agricultural and food producing countries and both countries encourage the development of a sustainable bio economy. The Dutch government and Dutch industry have both acted as driving forces in relation to the promotion of bio economy, and it may be relevant for the Danish government as well as Danish companies to exchange experiences with their Dutch counterparts.

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DCA - National Centre for Food and Agriculture is the entrance to research in food and agriculture at Aarhus University (AU). The main tasks of the centre are knowledge exchange, advisory service and interaction with authorities, organisations and businesses.

The centre coordinates knowledge exchange and advice with regard to the departments that are heavily involved in food and agricultural science. They are:

Department of Animal Science
Department of Food Science
Department of Agroecology
Department of Engineering
Department of Molecular Biology and Genetics

DCA can also involve other units at AU that carry out research in the relevant areas.

SUMMARY

The present report provides an overview of the major potentials and challenges in relation to an increased application of green biomass in Denmark. The report has been prepared with a view to acting as a part of the scientific basis of the National Bioeconomy Panel discussions on the potentials of green biomass.

The report e.g. points out the fact that green biomasses typically have higher yields and higher protein contents than grains. Therefore, green biomasses may be potential substitutes for soya imports if it is possible to extract the protein part commercially and create a feed that is competitive compared to soya. In addition, green biomass has a variety of potentials in the form of high-value products for feed and food ingredients. Conversion from cereal grain production to grass-based production entails a range of environmental potentials, including reduced pesticide use, reduced nitrogen leaching and an increased soil carbon stock.