



# THE + 10 MILLION TONNES STUDY

Increasing the sustainable production  
of biomass for biorefineries.

Updated Edition 2016



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# About the Plan

This report is an updated version of the + 10 mio tonnes study published in 2013. The need to create sustainable solutions in the energy sector initiated collaboration between scientists at the University of Copenhagen, Aarhus University and R&D staff from DONG Energy. An agreement on funding by DONG Energy for an independent study on expansion of Danish biomass production and its use for bioenergy was set up.

An important part of the study is how we sustainably can increase the production of biomass without undermining food and animal feed production. The study was published with the title »The + 10 million tonnes study«, and the results shows that it can be done through a joint effort and dedicated commitment towards sustainable technology and biology.

The report also describes the effects of the establishment of a Danish nationally sourced biorefinery sector. In order to realize the full technological and environmental potentials of an increased biomass production, further research and development is required, particularly within agriculture and forestry, but also within technology and infrastructure for biological and chemical conversion of biomass.

The work in the updated version of the study includes the latest developments within agricultural research as well as quantification of the effects upon greenhouse gas emissions. The work is done independently by researchers from University of Copenhagen and Aarhus University. The updated version is financed by the two universities with support from the two Innovation Fund Denmark projects BioValue SPIR and BIORESOURCE.

# Summary and solutions

Green growth and a conversion to a bio-based economy are crucial for the sustainable development in a world with limited resources. But how is it done in practice and what does it require, not just for the Danish economy and energy supply, but also in terms of effects upon environment and nature? Is it possible for Danish agriculture and forestry to produce sufficient biomass for a new biorefinery sector, without negative impacts on the environment or food production? Furthermore what would be the consequences of such a development for economic growth and employment as well as for greenhouse gas emissions?

These questions form the background for a comprehensive study of how environment, technology and economy can be combined to incorporate biomass in the transition to a green economy. A summary of the results is presented in this report. The study was a joint venture between University of Copenhagen and Aarhus University.

The background for the investigation was the question on whether it would be possible in Denmark to increase the production

of biomass from agriculture and forestry by 10 million tonnes. This increase should incur no reduction in food production, no expansion of the farmed area just as the solutions needed to have a positive impact on the aquatic environment and biodiversity. Preservation of soil fertility and carbon content were likewise important factors.

The report describes three scenarios:

- A business-as-usual scenario where we just increase the utilisation of the existing agriculture and forestry.
- A biomass-optimised scenario where both agriculture and forestry are adjusted to produce the maximum level of biomass.
- An environment-optimised scenario with emphasis on reducing nutrient leaching and where biodiversity is strengthened by the creation of conservation woodland.

For the business-as-usual scenario, the target of an additional 10 million tonnes of biomass is not achievable, while the biomass scenario reaches the target, and the environment-optimised scenario almost reach the target.

The results also show that it is feasible to make quite significant environmental improvements. The leaching of nitrate from agricultural soil can be reduced by approximately 23,000 tonnes and biodiversity would benefit in the environment-optimised scenario.

If the additional biomass is used in the Danish biorefinery sector, this would result in a production worth of 14 to 26 billion Danish kroner. This would create 12,000-21,000 new jobs, mainly within biomass production and industry. Many of the new jobs would be created in rural areas. Effects of income and employment from an associated technology export have not been included.

The combined effect upon greenhouse gas emissions of biomass production and its use within a biorefinery sector is large. A reduction of up to 20 % of the Danish Greenhouse gas emissions will be possible. The reduction originating from biomass production in agriculture and forestry would, however, be assigned to sectors other than agriculture and forestry.

The production from a Danish biorefinery sector using 10 million tonnes of biomass correspond to roughly 20 % of our current consumption of natural gas or 30-50 % of our petrol and diesel consumption. Feed protein would be an addition to our protein supply. The final levels will, however, depend on the technology development.

# Proposed solutions

It is possible to produce an additional 10 million tonnes of biomass by 2020 within the framework of our existing agriculture and forestry without any adverse impacts on food and animal feed production. It will also be possible to significantly reduce the environmental impact from agriculture and increase biodiversity in Denmark. This is feasible by:

- Increased recovery of field straw by 15 % through modest improvements to the harvesting equipment.
- Growing of cereal varieties with a higher straw yield.
- Doubling of the crop production per hectare by adopting cropping systems with a longer growing season using perennial crops such as willow or grass, or by double cropping.
- Reduced nitrate leaching from agriculture by shifting to more environmental benign cropping systems such as perennial crops, extended use of cover crops and increased afforestation.
- Increased recovery of biomass from forestry.
- Increase forest growth through breeding strategies and by using faster-growing tree species.
- Harvest of biomass from approx. 70,000

ha of wetland areas and in this way also improve biodiversity from stemming the encroachment of nettles and shrubs. Biomass and nutrients can likewise be harvested from approx. 7,000 ha of road verges, also here contributing to a more varied flora.

- Improved utilisation of slurry from livestock production.

For agriculture, the additional biomass can be generated by improving the recovery of straw, changing to cereal varieties with more straw, and finally by adopting new cropping systems. The first two initiatives could be implemented within a five-year period, while a large-scale transition to new cropping system is unlikely to be implemented until after 2020.

For forestry, the additional recovery of biomass could be implemented within a short time frame, while breeding activities and afforestation with new species obviously has a much longer horizon.

The proposed scenarios involve by 2020 approximately a 9 % reduction in the size of the area needed to produce the same level of food and animal feed as is currently produced. This is possible because one of

the expected co-products from the biorefining process is animal feed, and conversion of 10-15 % of the yellow and green biomass (straw and grass) to animal feed will compensate for the reduction in the area used for animal feed crops.

The biomass production in the scenarios corresponds more or less to the Climate Commission's estimates of available national resources for energy production by 2050. However, much depends on how efficiently the biomass is utilised and how much of it is used for animal fodder.

The process of introducing new cropping and harvesting methods and new crops to agriculture is complex, and its implementation will not happen automatically if farmers do not perceive advantages from it. An active collaboration between industry, farmer, authorities and research will therefore need to be established.

A selection and rejection aspect will also be important in the process. It is not unimportant which production systems are selected for growing large quantities of biomass if we also expect to achieve large environmental benefits. Nitrate leaching from annual cropping systems is for example approx. three times higher than from perennial cropping systems.

# Land use

The Danish landscape are dominated by agriculture (Figure 1). Of the 43,100 km<sup>2</sup> land area, 26,000 km<sup>2</sup> is farmland, equal to 62 % of the area. Woodland covers approx. 5,800 km<sup>2</sup>, equal to (14 % of the area), of which the majority is managed. The remaining approx. 11,300 km<sup>2</sup> covers areas for nature conservation and recreation, beaches, urban areas, buildings, roads, and other infrastructure.

## Biomass production

### Agriculture and forestry

Harvested biomass from agriculture and forestry amounts to approx. 18 million tonnes dry matter (Figure 2) of a total pro-

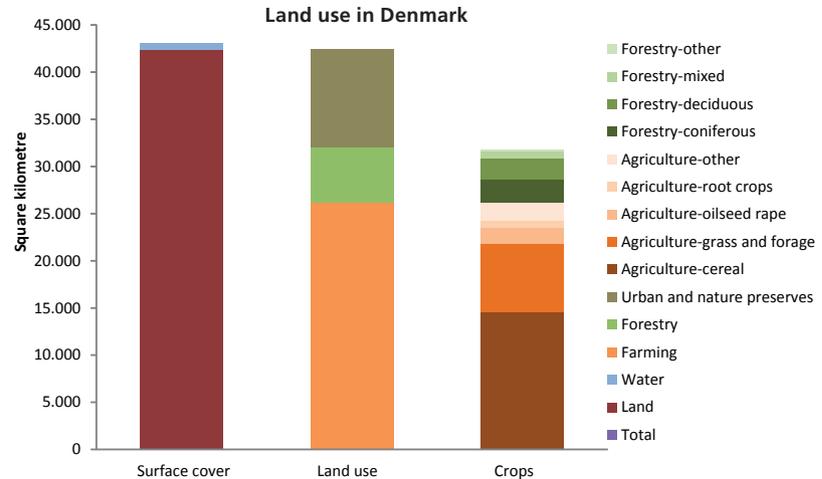


Figure 1. Land use in Denmark in 2009. Based on data from the Food and Agriculture Organization (FAO) of the United Nations and from Statistics Denmark.

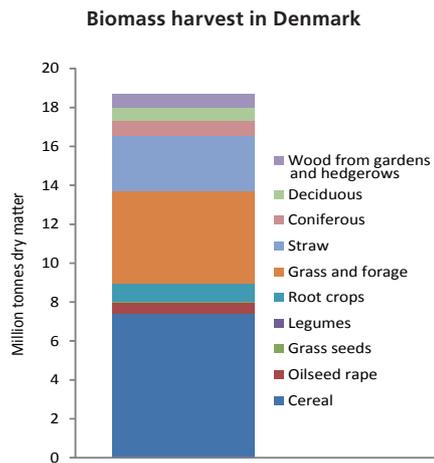


Figure 2. Biomass harvest from agriculture and forestry in Denmark in 2010. Based on data from Statistics Denmark and the Danish Energy Agency.

duction of about 20 million tonnes. The majority of this is made up of cereals, grass, forage and straw. In the Danish forests, approx. 1.5 million tonnes dry matter is harvested from a total above-ground production of 2.4 million tonnes. This means that 40 % of the above-ground biomass production in forests is used partly to increase the forest resource of timber and partly as unexploited biomass that is continuously recycled, some of which will eventually find its way into more permanent soil carbon pools. In agriculture, biomass is rarely stored in standing crops beyond the annual harvest, but a significant amount is left in the form of stubble, leaves, tops and unrecovered straw, which contributes to the soil carbon store.

### Other woody biomass

Trees also grow outside forests. Preliminary studies show that trees growing in hedgerows, along roads and railways, and in parks and gardens cover between 100,000 and 200,000 ha. The exact production from these areas is unknown, but probably constitutes a considerable resource. The harvest of firewood from hedgerows and gardens is an estimated 0.7 million tonnes dry matter.

### Waste

Total production of waste in Denmark was 13.9 million tonnes in 2009, giving a per capita production of 2.5 tonnes. Quite a large proportion of this is biological material

(Table 1). The Danish waste resources are already extensively utilised. Much of it is incinerated to produce heat and power. Some of the biological waste fractions are recycled for paper and cardboard production (paper and cardboard), compost (twigs, leaves, grass), chipboard (wood) and biogas (sludge). There is therefore no large untapped resource available that can help meet the target of an extra 10 million tonnes of biomass, but there is a large potential for increasing the fraction suitable for recycling through better sorting.

### Biomass uses

The primary production of biomass in Denmark is used for a variety of purposes (Figure 3). Important agricultural crops (by area and volume – cereal, grass and forage) are mainly used for fodder, while fruit and vegetables are usually used directly for human consumption. Roughly half of the harvested straw is used for energy production and the other half in livestock husbandry. The woody biomass is primarily used for energy purposes, either as firewood in private households or in the decentralised heat and power production. Of the timber production from forestry, 36 % is used in the wood industry.

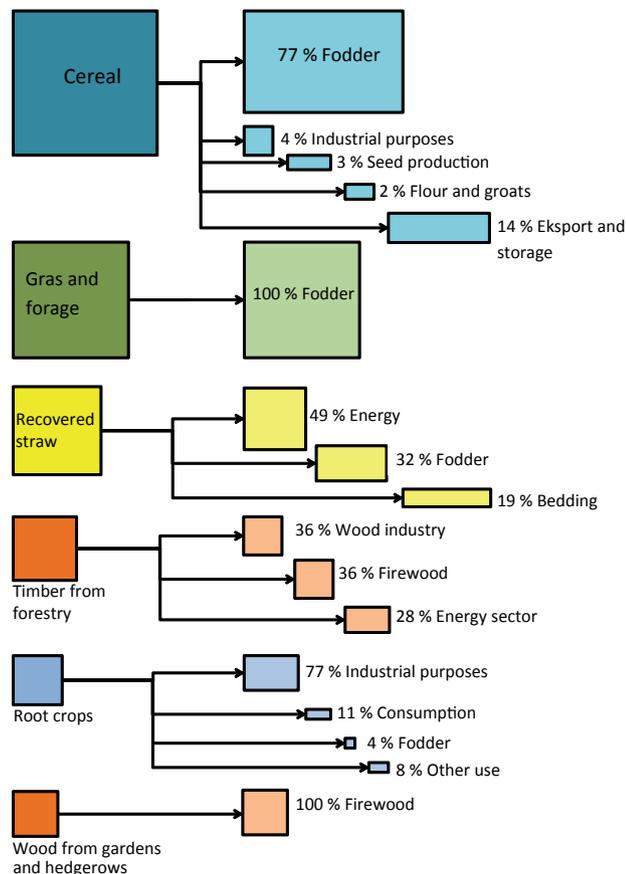


Figure 3. End use of the large (by volume) fractions of primary biomass production in Denmark.

Table 1. Production and utilisation of industrial waste fractions in Denmark in 2009. Based on data from the Danish Environmental Protection Agency.

Fraction	Usage	Fraction recycled 1,000,000 t (fresh weight)	Incineration, 1,000,000 t (fresh weight)	Landfill
Suitable for incineration			2,9	0,007
Paper and cardboard		0,7		
Food waste		0,2		
Twigs, grass, leaves		0,8		
Wood		0,1		
Sludge		0,6	0,3	0,02

# New technology can build synergy between crop use for feed, food and industry

Biomass mainly consists of carbohydrates and lignin. The carbohydrates can be divided into cellulose, hemicellulose, starch and sugars. The cellulose and hemicellulose are found in stems and leaves, while the starch is found in grains and seeds. Lignin is a different kind of organic material made up of phenols. The function of lignin is to provide rigidity and resistance to attacks from degrading fungi. Biomass also contains smaller quantities of proteins and oils, but these vary between the different kinds of biomass and even within the same species. This is a challenge for the conversion technologies for biomass, but it also enables a far wider application and adaptation of biomass to technology and vice versa.

Biomass waste is a mixture of different types of biomass, where food waste and paper make up the largest share. Waste from livestock production, better known as slurry, also contains a certain amount of organic acids in addition to the usual constituents.

## Biomass conversion

The conversion of biomass follows one of three basic pathways: thermo-chemical, biochemical or catalytic-chemical conversion. In the thermo-chemical conversion, the biomass is decomposed at a high temperature. If sufficient oxygen is available as in combustion, the conversion process will produce pure heat. If the oxygen is removed, the biomass converts to gas. This is called gasification. The gas can be combusted in an engine or turbine for power production or can be purified and converted into liquid fuels. Gasification is currently used for

heat and power production. The production of liquid fuels from gasification is still at an experimental and demonstration stage.

The biochemical fermentation of sugars into ethanol is a method commonly used for conversion of biomass, and is already used at industrial scale. Biogas production is also a biochemical conversion by fermentation. Biochemical conversion is characterised by the presence of living organisms such as yeasts, fungi or bacteria that via their metabolism convert the sugar, oil or protein in the biomass. Lignin cannot be biochemically converted.

Catalytic-chemical conversion is mainly combined with other conversion methods and changes the chemical structure of the biomass components. This could be the

conversion of hemicellulose into the chemical building blocks furfural or the conversion of crude vegetable oil to biodiesel by transesterification.

## Biomass and conversion processes must match

The composition of the biomass determines how it can be converted. Woody biomass has a low salt content but high lignin content and is therefore suitable for combustion and gasification. Biomass from straw and grasses has a higher salt content but lower lignin content and is therefore suitable for fermentation, for example to ethanol. To produce a high biogas yield, straw requires pre-treatment, while grasses, maize and their like are more easily converted.

It is possible to use a low temperature for the gasification of straw, but primarily for

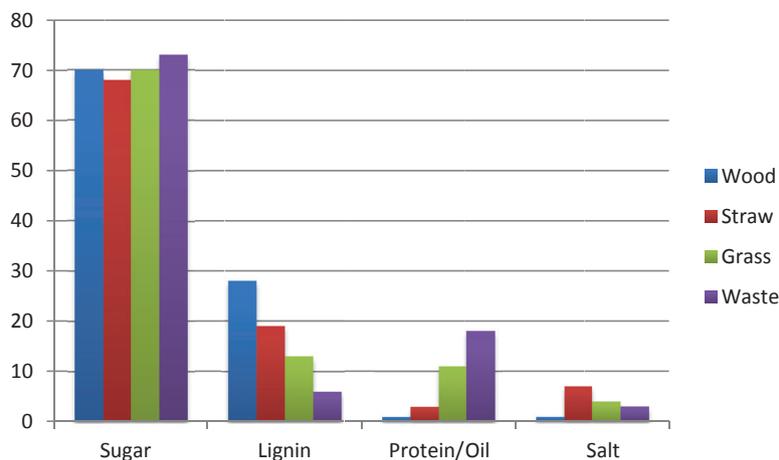


Figure 4. Typical composition of different biomasses. Data from Jørgensen et al. and Jensen et al.

the production of heat and power and not for other purposes. Another example is fermentation of wood. Coniferous species can be converted to ethanol, but the high lignin content reduces the efficiency and increases costs.

Biomass with very high water content such as slurry and household waste is less suited for combustion or gasification. It is possible albeit at a relatively large conversion loss. Conversely, these biomasses are well suited for the biogas process.

### **Conversion of biomass can retain or degrade nutrients and feed value**

When biomass is converted through incineration or gasification, all the nitrogen is lost. Incineration and high-temperature gasification will render the phosphorus unavailable to plants. Low-temperature gasification retains the phosphorus and potassium, but the nitrogen is lost in the process. Biological conversion of the biomass retains all the nutrients in a form that is available to plants and these can be returned to crop production, if desired.

Wood and straw have low contents of nitrogen and phosphorus compared to slurry and household waste. The recycling of nutrients is particularly important if the biomass is nutrient-rich.

If the biomass contains protein or oils of feed quality, these will be preserved and typically improved when the biomass is converted to ethanol. All or most feed components are unavailable or destroyed by biogas, incineration, gasification or digestion.



PHOTO: UFFE JØRGENSEN

### **Optimised conversion of biomass**

It is possible to coordinate biomass and conversion process to produce not only energy but also food, animal feed and other non-food materials. The nutrients can also be recycled to the fields and forests from whence they came. This is known as biorefining and has a large potential in terms of both economy and sustainability. The technology is still in its infancy, but the basic processes have been developed.

The principle is to use the biomass components where they have the largest merit and therefore typically also the largest value. In practice this means that cellulose and hemicellulose are converted to sugars and fermented to fuels and chemicals. Lignin has to be combusted for the production of heat and power or gasified and refined to fuels and biomaterials, and proteins and oils have to be extracted for food and ani-

mal feed. When no further extractions from the biomass are possible, the residue will be converted to biogas in a blend with waste and slurry.

There are different technology platforms for the conversion of biomass: A sugar platform, a lignin platform and a gasification platform. A biorefinery will have all three platforms and will combine these to achieve the maximum yield of energy, animal feed and materials. While the respective technologies have been developed, work is still needed for their maturation and integration.

An important aspect in the use of new technology for optimised conversion of biomass is that it will require less land. By an optimal use of the components in the biomass, more services can be produced per unit land area. This is an important and valuable point when talking about environmental pressure and efficient use of resources.

# Preconditions for a larger biomass production

With the help of new technology in the form of biorefineries, an effective production of biomass from forestry and agriculture will be a central and crucial platform for the development of a bio-based economy.

This will place a demand on the ability of agriculture to increase the supply of biomass in a sustainable and ethical way without adversely impacting the supply of animal feed and food resources. The question also arises whether this is actually possible within the current legal framework.

Current production of harvested biomass from Danish forestry and agriculture is approximately 20 million tonnes dry matter. Most of the production from agriculture is used for food and animal feed and only a minor amount are used for energy and industrial purposes. From forestry approximately half of the production goes to timber and the other half directly to energy production.

Agriculture is regulated by a number of measures for protecting nature and the environment, which combine to form the legal framework for the production potential in agriculture. The primary objectives are to protect the quality of the aquatic environment, the basic production resources, and nature habitats. There are therefore general restrictions on the use of fertilisers and pesticides in agriculture and different restrictions on the cultivation of environmen-

tally sensitive or valuable nature areas. It is, for example, an important part of the implementation of the EU Water Framework Directive to reduce impacts from agriculture.

Other important legislation is the regulations in the use of animal manure and the requirement to include cover crops in cereal crop rotations in order to reduce nutrient leaching.

Forestry has fewer regulations, but via the Danish Forest Act a large proportion of forestry has to be kept as sustainable forestry. The use of fertiliser is restricted to a few young plantations.

Within the existing legal framework, there are therefore relatively few opportunities for increasing the production of biomass via an intensification of the current production using measures such as fertilisation and pesticides.

On the other hand, there is a considerable potential for increasing the production of biomass through altering production systems, selecting crops and varieties and a differentiated land use. Many of these initiatives are possible within the existing legal framework, while others would require an adaptation of the regulations towards a



PHOTO: YIVIAN KVIST JOHANSEN

more differentiated regulation. This could be in the form of a less intensive cultivation of sensitive areas and intensive cultivation of more robust areas.

There is a political desire to promote a more sustainable agriculture while increasing the overall use of biomass for energy and industrial purposes in a move towards a greener society and a bio-based economy.

The Green Growth action plan, which was endorsed in 2010, is a manifestation of this desire, where agriculture is a cornerstone as a supplier of renewable energy.

In the years to come a number of changes to the EU Common Agricultural Policy can also be expected with a move towards a more sustainable green practice. From 2016 a new Danish AgroEnvironmental Action plan is implemented, but the present results are estimated for the situation before this implementation

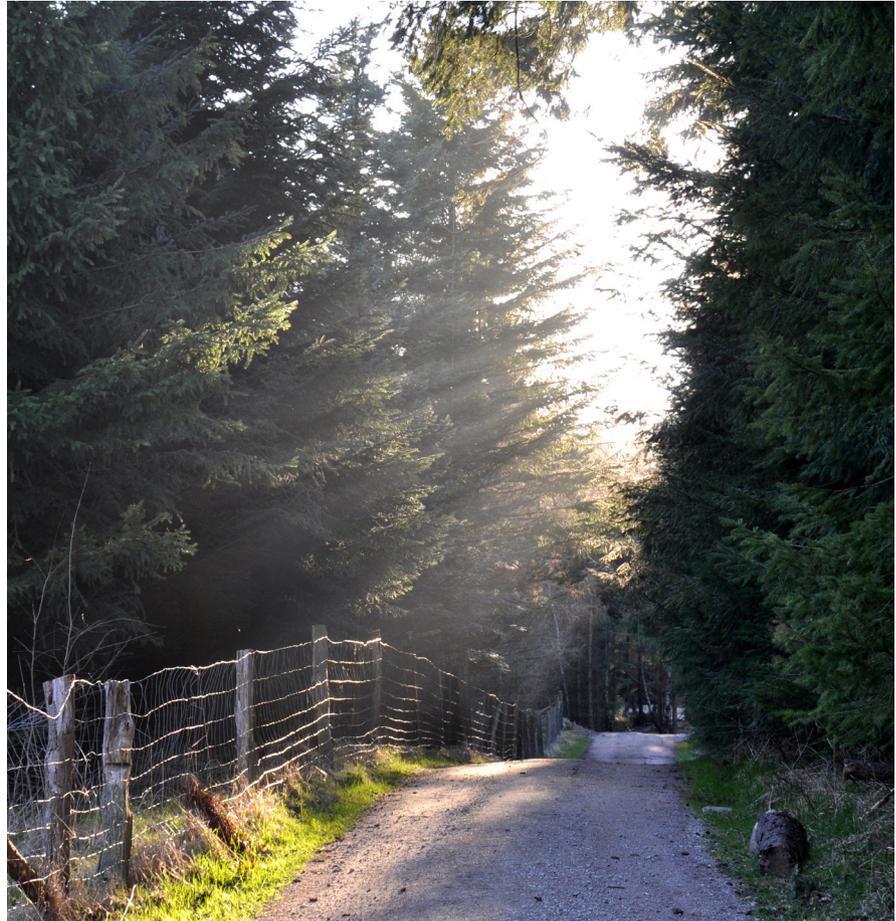


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# We can double biomass production using smarter cropping systems

It is possible to recover more biomass from existing crop rotations and forestry using relatively simple measures. It is also possible to design completely new crop rotations designed for biorefining applications that will give an even higher biomass yield while also reducing environmental impact (see later sections).

## Make the most of the summer sun

Cereal crops do not fully utilise the solar radiation in the growing season, since in the months of July to September they are maturing, harvested, ploughed and reseeded. Crops that remain green and productive throughout the growing season (grasses and trees, for example) therefore have a higher yield potential. Sugar beet, too, manages to utilise much of its total yield potential, despite making a late start in the spring. If all the solar radiation in the growing season were utilised for biomass production, it would theoretically be possible to produce more than 30 tonnes of dry matter per hectare in Denmark. Dry matter yields of the most common crop in agriculture today – wheat – is less than 10 tonnes per hectare when combining grain and straw, so there is a large potential for a more effective storage of solar energy in biomass.

A better utilisation of the solar radiation could be achieved by harvesting the cereal before maturity and store it in airtight silos. This could give a larger, and possibly more readily convertible, straw yield, and could be followed by the sowing of a cover crop or another main crop mid-summer.

## More effective photosynthesis

In a warmer climate it may be relevant to use crops that have the so-called  $C_4$  photosynthesis, which under higher temperature regimes have a 30 % more efficient conversion of solar radiation than  $C_3$  crops. Maize is the only widely used agricultural crop that has this ability and maize is very productive despite its relatively short growing season. Miscanthus, which is grown quite extensively in the UK but not widely in Denmark, has a more cold-tolerant  $C_4$  photosynthesis than maize and can therefore benefit from solar radiation over a longer period of the year. In a study carried

out in the North American corn-belt, miscanthus produced 60 % more dry matter than maize over the growing season. Another option for full exploitation of the sunlight in Denmark is to grow maize with  $C_4$  photosynthesis in the summer and a cold-tolerant  $C_3$  crop in winter and spring (winter rye, for example).

Through the development and utilisation of these different options, the total yield of biomass can potentially be doubled to 15-20 tonnes dry matter per hectare. If the biorefining of this twofold increase in production also includes animal feed products



PHOTO: UFFE JØRGENSEN

in addition to materials and energy, then the current food production in Danish agriculture could be maintained.

### The easy options

In the short term it is also possible to increase yields from existing production systems. The current varieties of cereals have all been selected for maximum grain yield over many years of breeding. More straw has been produced in the process than has been recovered and farmers have had no incentive to grow straw-rich varieties. Several studies show, however, that it is possible to increase straw yield by changing the variety without impairing grain yield. If straw becomes a desirable commodity and therefore carries a higher price tag, it will be attractive for farmers to change to straw-rich varieties.

That straw has not been a primary product in cereal production is reflected in the harvesting process jettisoning most of the stalk onto the field. Particularly the small parts such as husks and leaves are not recovered. By changing the design of the combine harvesters or by using whole-crop harvest or stripper harvest, the amounts of straw recovered can be increased by 12 to 30 %.

### Genetically improving forest trees

The deciduous tree species commonly used in Denmark have rarely been genetically improved – with the exception of poplar. For conifers there has been breeding programmes on in particularly Norway spruce



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and Sitka spruce, but also on larch and to a lesser extent on Douglas fir. These breeding programmes have, however, focused on important traits for the timber production, such as straightness and wood properties and not on biomass productivity. A broad genetic material is therefore available and is undergoing testing.

Compared with the breeding of agricultural crops, forest tree breeding requires much longer time as trees take several years to reach the reproductive stage. Denmark has been one of the pioneers in tree breeding and the work of initially Forstbotanisk Have and later on of Arboretet has been groundbreaking. The very large pool of trials and

knowledge on the production capacity of individual tree species that has been collected over time is barely utilised. For the most common conifer species in Denmark it is estimated, that the timber production can be increased by 25-35 % using genetically improved material.

Of the cultivated trees in Denmark, particularly the introduced conifers have a large volume production. One of the reasons is that conifers, except for larch, do not lose their productive apparatus (needles/leaves) in the autumn and are therefore able to utilise the solar radiation over a longer period than the broadleaved species and most agricultural crops.

# The three scenarios

In the analyses we compare, in three scenarios, an increased biomass production and utilisation in year 2020 with the production and utilisation in year 2009. In the business-as-usual scenario, we assume an increased utilisation of the already available biomass in, for example, straw, slurry and rape seed oil, but with no technical optimisations of harvesting technique or with species or variety selection.

In the biomass-optimised scenario we perform a number of optimisations to increase the biomass quantity and in the environment-optimised scenario a number of additional measures are implemented to promote sustainability in the form of, for example, reduced nitrate leaching, increased soil carbon storage and biodiversity.

A brief overview of the features of the individual scenarios is set out below. In none of the cases has the entire co-product resource been included (straw, slurry, meadow grass and road verges), as a maximum utilisation rate of 70-80 % of the resources has been assumed. For details on the assumptions used, please refer to the background material ([www.foi.life.ku.dk/publikationer](http://www.foi.life.ku.dk/publikationer) in Danish only).

## Business-As-Usual (BAU)

- No changes to species or variety or harvesting technology but the residual biomass (straw, slurry and meadow grass) are utilised.
- Historical increase in yield, fodder efficiency, area use for roads and towns, and organic farming included (corresponding

to the assumptions of the Climate Commission). Future changes to the EU common agricultural policy are not included.

- Export and import of cereal, soya, etc., are not included in the biomass potential.
- Existing stands of perennial energy crops are projected.
- 1900 ha afforestation per year.
- Same species composition as existing forests.
- Increased mobilisation of wood biomass but growth exceeds harvest.

## Biomass-optimised (Biomass)

- Conversion to cereal species producing 15 % more straw.
- Increased recovery of straw (15 %) via modification of harvesting technology.

- Oilseed rape on arable farms is replaced by sugar beet (dry matter yield 14 t roots + 5 t tops).
- Wetland areas are allowed fertilisation to maximise grass yield.
- A grain area the same size as that converted under the Environment scenario (approx. 149,000) is converted to sugar beet.
- Road verges, water weed clearing, and cover crops are utilised (area under cover crops is projected as a result of Green Growth and the stipulations attached to the environmental approval for livestock holdings).
- 1900 ha afforestation per year.
- Extensive use of faster-growing tree species such as nurse trees, for example in



PHOTO: UFFE JØRGENSEN

mixed woodland and new plantings.

- The gains achieved from genetic improvements of trees are utilised.
- Coniferous forests are regenerated with conifers and deciduous forests with 50 % broadleaf, 50 % conifers.
- Greatly increased recovery to wood biomass of roughly the same size as growth.

### Environment-optimised (Environment)

Same as Biomass-optimised, except for:

- No straw removal from areas with critically low soil carbon content.
- Increase in area with cover crops (81,000 ha).
- Perennial energy crops replacing beet (by 2020 expected yield is 15 t/ha with later yields projected to reach those of beet).
- No cereals in areas with nitrate retention below 35 % – instead perennial energy crops.
- Wetland areas not to be fertilised (except possibly with potassium).
- 4500 ha new woodland plantings per year.
- The gains achieved from molecular breeding of trees are utilised.
- 47,000 ha deciduous woodlands more than 100 year old reclassified to conservation woodland.
- Deciduous woodland is regenerated with broadleaves, and conifers in a 50:50 conifer to broadleaves ratio.
- Harvest of timber considerably less than growth.



### Basis for calculations

Data for agricultural land use in Denmark, yields, livestock manure production, etc., have been obtained from a number of databases: The general agricultural register (GLR), the central livestock register (CHR), StatBank Denmark, DJF geodata, information from fertiliser accounts, applications under the single payment scheme at the Ministry of Food, Agriculture and Fisheries, GIS maps of roads, watercourses, urban and wooded areas, digital field maps, maps of the ability of different localities to retain nitrogen, and maps of the relationship between clay and carbon content (Dexter Index). These data have been integrated in a spreadsheet model and form the background for the projections of potential biomass utilisation in 2020 in the three scenarios.

In the case of forest biomass, the main elements are the extent of afforestation and land set aside as conservation forestry, choice of crop and cultivation method, and the mobilisation of wood biomass. The scenarios build on data from the National Forest Inventory, growth models and on general distribution ranges that reflect the utilisation of biomass.

# New research to validate the assumptions behind the scenarios

Targeted research to examine whether the preconditions of the +10 million tonnes plan scenarios are valid has been launched in recent years. At Aarhus University field trials with a variety of crops, optimized crop rotations and with changes in harvesting and establishment timing have been established. The tests include several locations to cover the variation in soil types and climate. Biomass yield is recorded as well as but as a number of parameters on the environmental impact: nitrate leaching, water consumption, carbon development in the soil over time, as well as changes in the pool of weed seeds and disease incidence in the different crops and crop rotations.

The first results confirm that by a change in crop composition it will be possible to increase the annual biomass yield significantly - potentially doubling. Especially beets and grass have very high yields. The first measurements of nitrate in ground water below crop root zone shows large differences, and again the beets and grass give the best results with low nitrate concentrations.

In the trials full fertilized pure grass is compared with grass clover, where only P and K fertilizer are applied, as clover can fix N from the air. The first results showed substantially higher yield in the pure grasses fertilized with 425 kg N / ha than in the unfertilized clover. Despite the high N fertilization, the average nitrate concentration below the pure grass was the lowest of all treatments - though only marginally differ-

ent from the unfertilized clover (see Figure 5). Analyses of the N content of the harvested grass found a larger N-recovery than applied with fertilizer. There is accordingly a highly efficient N-utilization in a system with very large N-dynamics and productivity, which could ensure a sustainable intensification of Danish agriculture if the produced biomass can be used for valuable products. The project analyses for each crop the content of easily-extractable protein in order to assess the potential for launching a Danish production of protein feed based on green biomass. In the winter, 2016-2017 we will feed pigs and hens with the new protein product to test its practical performance. For selected crops the correlation between the volume of pro-

duction and its resultant nitrate concentration in runoff soil water is shown in the Figure 5 below. It shows two paths of development to reduce nitrate loss from Danish farming. The first is a reduced input and production of clover, which provides a clear reduction in nitrate losses compared to cereals. However it may result in a reduction in total biomass yield. The second is a transition to crops that provide much greater biomass yield and with equal reduced nitrate loss. It is accordingly not the supply of fertilizer for the crops that are the main cause of nitrate losses, but of much more impact is the choice of crops to cultivate.

The different crop systems should of course be thoroughly examined for their total en-



Research field

environmental impact and possible economic sustainability. There is a cost both financially and environmentally to manufacture and use N-fertilizer, which should be included in the evaluation. Other parameters such as biodiversity may react differently to the choice of crops. Furthermore, the crop effect on the development of soil carbon has an effect on the overall greenhouse gas balance - even though smaller than the effect of biomass substitution of fossil fuel - and the experiments will in the years to come provide answers to some of these

questions. The very large and clear differences between crops total biomass production and nitrate leaching underpin the selected preconditions of +10 million tonnes plan and suggest that it is possible to both increase productivity and reduce environmental impact (Figure 5). This can be done by switching to crops that better exploit solar radiation throughout the growing season, and which are better at keeping the nutrients in the production system as they have live roots in a greater proportion of the year.

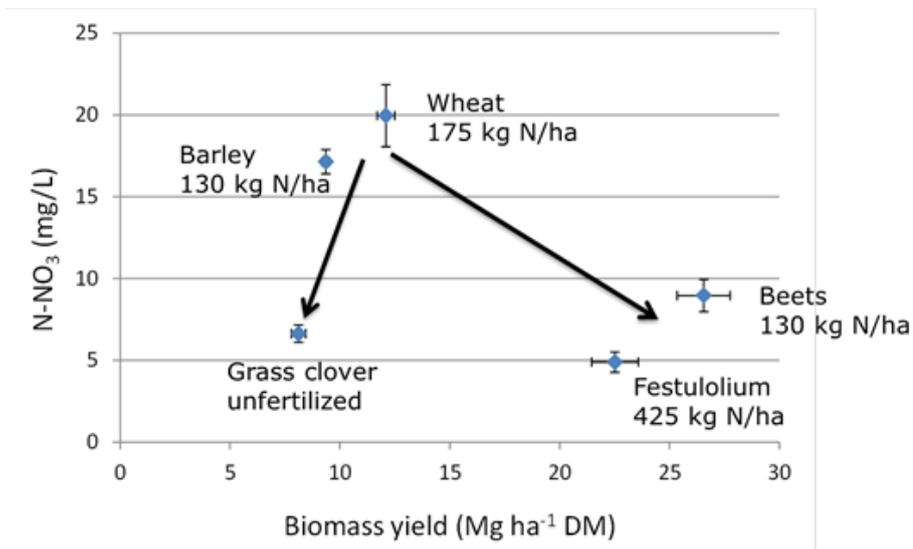


Figure 5. Mean nitrate concentrations in soil water below the roots in autumn and winter following the production year 2013 versus crop dry matter yields. N fertilizer application in 2013 is given for each crop. Bars indicate  $\pm$  SE. Possible development routes for reducing nitrate leaching from the current cereal based production systems indicated by arrows (From Bath et al., 2016. *Perennial Biomass Crops for a Resource Constrained World*, Springer).

# An additional 10 million tonnes biomass can be produced

The scenarios (Figure 6) show that a heavier exploitation of the existing biomass production (BAU scenario) can yield approximately 4 million tonnes of dry matter per year in addition to the almost 4 million tonnes already recovered in agriculture and forestry. By implementing a number of optimisations, it will be possible to increase biomass supply by a further 6 million tonnes dry matter (Biomass scenario). By incorporation of nitrate leaching, soil carbon and biodiversity considerations in the biomass production (Environment scenario), a total of well over 11 million tonnes of dry matter could be produced. The largest potential source of additional biomass is agriculture.

For the contributions from agriculture, the additional biomass can be found through an improved recovery technique for straw, a change towards more straw-rich varieties, and finally through new cropping systems. The first two initiatives can be implemented within a five-year period, while the implementation of a large-scale transition to new cropping systems cannot be expected until after 2020.

For forestry, the BAU scenario shows that an additional 0.8 million tonnes dry matter per year can be collected by 2020, corresponding roughly to a doubling of the forest biomass. By implementing a number of optimisations (Biomass), biomass from forestry can likely contribute an additional 0.75 million tonnes dry matter. This is primarily through an increased mobilisation and active use of other tree species and new cultivation systems. In the Environ-

ment scenario the biomass potential is approx. 0.15 million tonnes higher than in the BAU scenario in 2020, primarily because of the additional planting of trees.

The different kinds of biomass can be divided into five main categories, each destined for specific energy technologies (Figure 7). Yellow biomass is straw from cereal crops, oilseed rape and seed grass and is currently the largest source of agricultural biomass. Straw is mainly burnt, but a small amount is used in biorefining in a biological process. The utilisation of yellow biomass may be improved, and with the use

of relatively simple measures such as different species and optimisation of the recovery of straw, this category should be able to contribute twice as much as it currently does.

The largest potential is found in green biomass (grass, beet, and the like), which has a high water content suitable for biological transformation. The full utilisation of this potential will require crop changes in agriculture, the development of harvesting and storage techniques for large quantities of green biomass and effective conversion techniques. Much of the green biomass

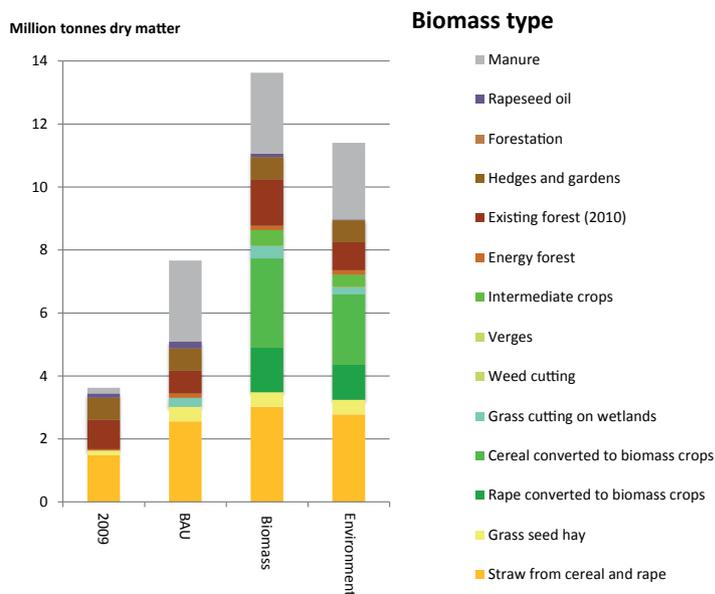


Figure 6. Estimated total biomass potential from agriculture and forestry in the three scenarios for 2020, and the utilisation for energy in 2009.

can via the choice of crops be changed to the brown biomass category (willow, poplar or other woody plants), which is better suited to thermochemical conversion. Another option is to plant vigorous perennial grasses (such as miscanthus), which can be harvested green in the autumn or dry in the spring (yellow category). Finally, there is a considerable potential in animal manure (grey category), which is best suited for conversion to biogas.

This report does not (except for road verges and water weed clearings) draw up scenarios for developments in the production

of biomass from waste or from areas other than from agriculture and forestry. The existing production of woody biomass from hedgerows and gardens of an estimated 0.7 million tonnes dry matter is expected also to be available in 2020. The Environmental Protection Agency expects the amount of waste to increase from 13.9 million tonnes in 2009 to approx. 15 million tonnes in 2020 and then peak at 17.5 million tonnes around 2040. Although these numbers are not separated into waste fractions, we can expect the source of waste biomass available for biorefineries to grow in the future.

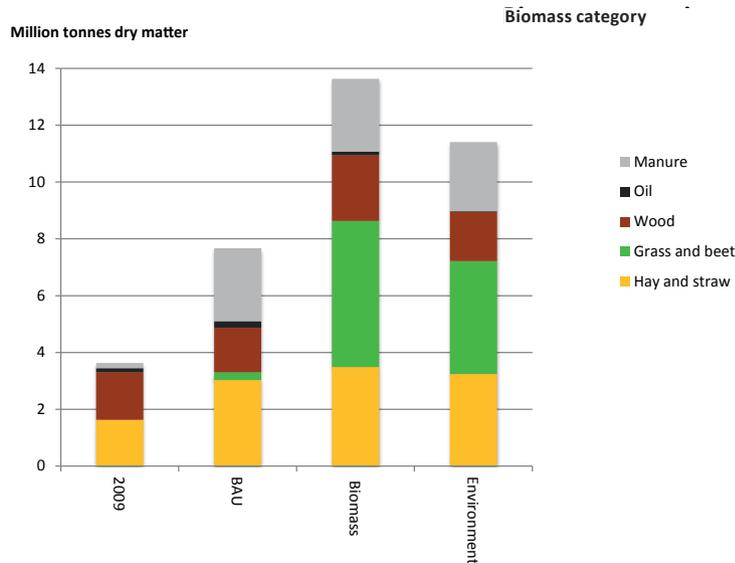


Figure 7. Biomass categories in the scenarios and in 2009. Yellow biomass is hay and straw, Green biomass is grass and beet. Brown biomass is wood. Grey biomass is animal manure. Oil is rapeseed oil.



# Land use change

Implementation of the scenarios will have implications for how the 2.7 million ha of farmland is used (Figure 8). By 2020, the farmed area is expected to be diminished to 2.6 million ha, as land continues to be increasingly used for roads, housing and forests. In 2009, approx. 0.04 million ha was used for bioenergy production, primarily rapeseed oil for biodiesel (we have calculated with 40 % of the area with oilseed rape being designated for bioenergy pro-

duction, as approx. 60 % of the yield is rapeseed cake which is used as fodder). In the Biomass and the Environment scenarios, the area producing biomass for power plants and biorefineries increases to just under 0.4 million ha. This means that the area for food production will be reduced by approx. 0.2 million ha as the productivity from the remaining area is estimated to increase. Some of the area lost from food production – namely 0.07 million ha per-

manent grass on wetland soils – is, however, currently extensively farmed.

The biorefineries, on the other hand, will be able to produce animal fodder, which can replace some of the cereal that is used for animal fodder today. If 10-15 % of the dry matter in yellow and green biomass is converted to animal feed, both the Biomass and the Environment scenarios will achieve



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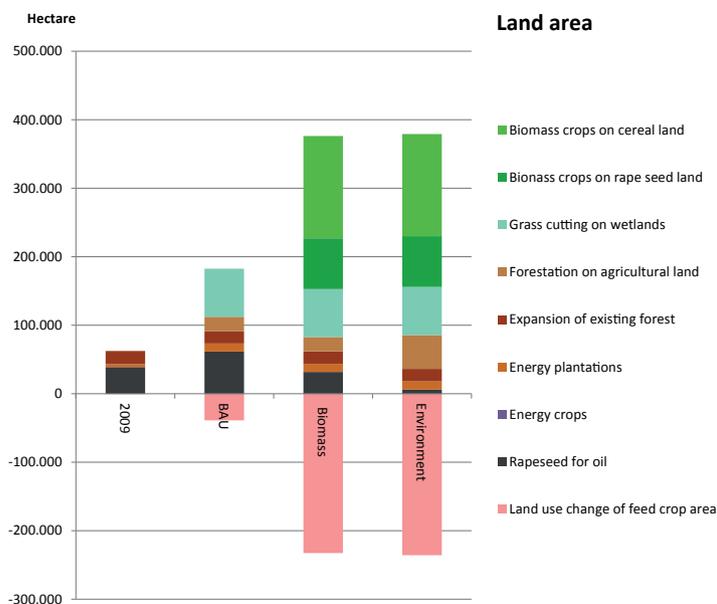


Figure 8. Land area dedicated to biomass production in Danish agriculture in 2009 and changed use in the three scenarios for 2020. Also shown is the net effect on the area needed to produce the same amount of fodder and food as in 2009.

a comparable feed production to what is lost from the reduced area with cereal and rape.

A characteristic of the forest cover in the scenarios is the slow transition to new production targets. With a longer time frame the Biomass scenario will be able to produce 2.1 million tonnes dry matter from forestry in 2100, while the Environment scenario would produce 1.7 million tonnes and the BAU scenario 0.95 million tonnes per year (Figure 9).



PHOTO: PALLE MADSEN

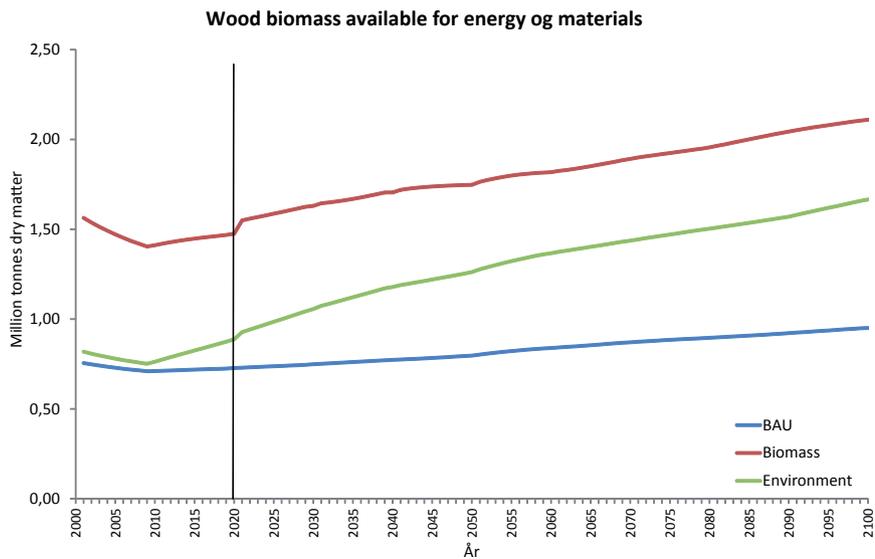


Figure 9. Development in the amount of wood biomass available for biorefineries from 2000 to 2100 in the three scenarios.

# What will be the environmental impact of an increased utilisation of biomass?

Production and utilisation of biomass for biorefineries can be controversial, because it will interact with the production of timber and food and with nature, environment and landscape. It is often assumed that the utilisation of biomass has an adverse impact on the environment, nature and landscape – and there are certainly examples of this. But biomass production can also have positive effects. There is, however, a need for more knowledge on the effects and for political control that ensures that prudent long-term solutions are favoured over more short-term beneficial solutions. That it is sometimes economically advantageous to choose solutions that do not provide social services in the form of environmental improvements is because the cost of the impact on the environment is rarely factored into the product price.

## Nitrate leaching

Reduction in nitrate leaching from agricultural soils is an example on how the environment can be improved with an increase in the utilisation of biomass. Less nitrate leaching is a highly prioritised area in Danish and European policies, which has been addressed in several national action plans and now in the Water Framework Directive. We have calculated that the implementation of the three scenarios can reduce nitrate leaching from agricultural crops by between 7,000 and 23,000 tonnes nitrogen per year (Table 2). This compares with a figure for total nitrate leaching of estimated 165,000 tonnes of nitrogen in 2011. Measures are still needed to meet half of the target for nitrogen in the Water

Framework Directive. The Environment scenario would approx. be able to deliver the remaining. In the BAU and Biomass scenarios, the energy utilisation of dry matter in animal manure contributes most to the total reduction in nitrate leaching. In the Environment scenario, most of the reduction in leaching is achieved by changing to cropping systems with better nutrient retention (perennial crops, extended use of cover crops and increased afforestation).

## Selection and rejection are important

There are many other environmental impacts associated with agricultural production and the effects of increasing the production of biomass may not all be positive. For example, the increased use of carbon in

animal manure and straw means that less carbon is returned to the soil. The replacement of rape or cereal with perennial biomass crops will, on the other hand, increase soil carbon input. Pesticide use is high in sugar beet and rape cultivation, but low for grass and other perennial biomass crops. The planting of trees uses practically no pesticides. The loss of phosphorus to the aquatic environment is primarily caused by soil erosion. On high-risk erosion areas, the use of perennial crops is therefore generally recommended to give a better protection of the soil surface. If an overall positive effect on the environment is to be achieved, informed choices must be made and crops selected or rejected.



PHOTO: UFFE JØRGENSEN

## Biodiversity

Biodiversity, or ecosystem variety, are very broad concepts, why clear effects on these are difficult to describe. Areas under production will, however, often have less diversity than natural areas, if these are not suffering from a nutrient overload, as is the case for many meadows and road verges today. The harvest on approx. 70,000 ha of permanent grassland on wetland soils and 7,000 ha road verges in the Biomass and Environment scenarios will remove nutrients and can therefore help improve biodiversity. The establishment of perennial biomass crops to replace some of the area now grown with rape seed and cereals in the Environment scenario can help improve biodiversity at the landscape level, since some species ( e.g. earthworms) prefer areas where the soil is less disturbed. Rarer plant and animal species are primarily found in dedicated nature conservation



PHOTO: THOMAS NORD-LARSEN

areas, including meadows from which nutrients are removed with the harvesting of biomass.

Without human interference, Denmark would be covered mostly by forest and much of the biodiversity under threat is associated with forest habitats, in particular

ancient forests. The amount and composition of the forest thus has a large influence on biodiversity. The native tree species (beech, oak, ash, Scots pine and yew, for example) are generally better for supporting biodiversity than the introduced species (maple, Norway spruce, Sitka spruce, Douglas fir). In the Environment scenario 47,000 ha of old broadleaf woodland will be designated for conservation purposes.

This will have a positive effect on the biodiversity in the forests. The rate of afforestation is also accelerated from the current 1,900 ha per year to 4,500 ha per year. In the short term this will benefit nitrate leaching (see Table 2) and soil fauna, and in the longer term it will also benefit biodiversity generally.

The Biomass scenario assumes that higher priority is given to the growing of coniferous rather than deciduous trees. Such a development of the species composition of the forests will on the whole have a negative impact on biodiversity.

Table 2. Estimated effects for the scenarios on nitrate leaching from farmland (tonnes N/year<sup>1</sup>).

Biomass type	BAU	Biomass	Environment
Animal manure	-5,752	-5,752	-5,487
Energy forest (willow, poplar)	-248	-248	-248
Replacement of rape area with biomass crops		-3,142	-6,085
Replacement of cereal area with biomass crops		775	-5,040
Afforestation	-847	-847	-2,005
Cover crops			-4,212
Total	-6,846	-9,214	-23,077

<sup>1</sup>Calculated based on the 2009 situation for the regulation standards before the new agro-environmental reform implemented from 2016)

### Indirect land-use change

The effect on nature and environment in Denmark is one aspect, quite another is the indirect effect in other countries – an issue that is subject of much debate. If a reduction in food production in Denmark leads to nature reserves in other parts of the world being put under the plough, the total effect on greenhouse gas emissions, nature and environment could be negative. However, the production of energy and materials need not lead to a reduction in food production. This requires that we succeed in growing crops destined for having twice the yield of cereals and oilseed rape, as well as produce food and fodder ingredients in the biorefineries.

Another example is the utilisation of wheat straw for bioethanol, fodder and solid fuel. The fodder fraction based on the hemicellulose from straw will add 10-20% to the production of fodder, which is in addition to the fodder made from the grain. A smaller area is therefore needed to produce the same amount of fodder, while energy in the form of liquid and solid fuels is produced simultaneously.

### Storage or displacement of carbon?

Forests differ from agriculture in their capacity to store large quantities of carbon in living biomass. The average volume of

wood in Danish forests is 199 m<sup>3</sup> per ha, corresponding to 68 tonnes carbon per ha. This is a large quantity of biomass compared to the European average of 107 m<sup>3</sup> per ha, but more can be achieved. It is relatively easy to increase the carbon stored in forests by ceasing felling and utilization of forests, but if carbon storage is preferred the level of fossil fuel and materials replacement is reduced. In the longer term,

the forests will reach a new equilibrium and thus no longer store carbon. The exact timing and the level of carbon storage equilibrium is not known.

The Environment scenario assumes a faster rate of afforestation and a lower utilisation of the forests and has a large potential for carbon storage in living biomass. It is estimated that by 2020 the Environment sce-

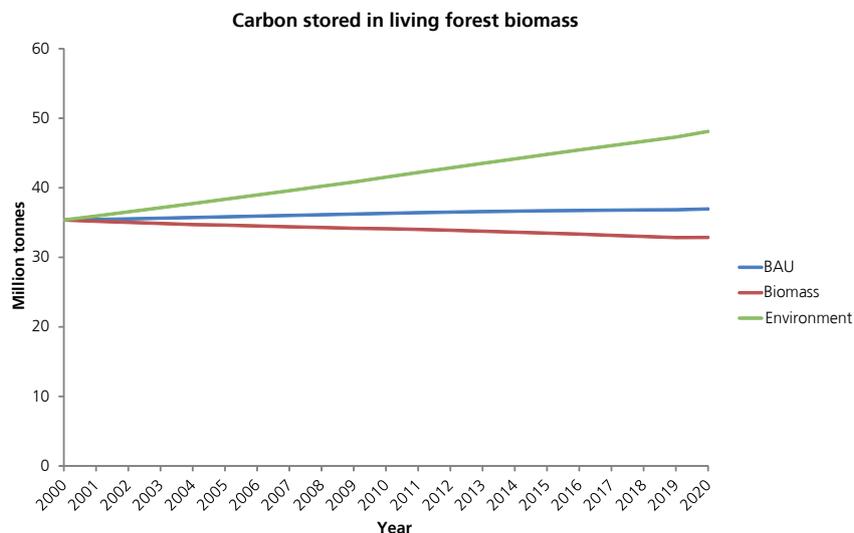


Figure 10. Amount of carbon stored in living forest biomass in the three scenarios.

nario will lead to 48 million tonnes carbon stored in living forests compared to 33 million tonnes in the Biomass scenario. The annual biomass production potential in the Environment scenario is, however, correspondingly lower at 0.89 million tonnes dry matter in 2020 compared to 1.47 million tonnes in the Biomass scenario.



PHOTO: PALLE MADSEN

# Greenhouse gas emissions, what is the reduction potential?

An increased biomass production for energy applications will reduce the emission of greenhouse gasses (GHG). The reduction is mainly caused by the substitution of fossil fuels with biomass, but also changes in land use and agricultural practice will affect soil carbon levels as well as CH<sub>4</sub> and N<sub>2</sub>O emissions. Here we show the combined effects of the three scenarios upon greenhouse gas emissions and compare them to the estimated Danish emissions in 2020. Reduced emissions from fossil fuel substitution is caused by the replacement of fossil carbon emissions that accumulate in the atmosphere, with biogenic carbon from mainly agricultural residues which moves in a one year biological cycle. Biomass is, like all other types of renewable energy, not fully CO<sub>2</sub> neutral as fossil fuels are used for transportation, farming and fertilizers. Typically, the effect of substitution is in the range of 60-95 % CO<sub>2</sub> reduction when biomass replaces fossil fuel resources. Changes in the management and use of land, known as LUC (Land Use Change), may change the CO<sub>2</sub> emissions when new crops or changes in agricultural practices affect the input and output of carbon to the soil. Over a period of typically decades, a new equilibrium of soil carbon level will be reached. The same effect can be seen on emissions of CH<sub>4</sub> and N<sub>2</sub>O, which mainly are caused by changes in fertilizer use as well as management and handling of manure. The total effect of land use change can be either positive or negative depending on the release or accumulation of soil carbon as well as CH<sub>4</sub> and N<sub>2</sub>O. Indirect effects of land use change (ILUC –

Indirect Land Use Change) can also be included in the calculation of GHG emissions from the scenarios. The market for food and feed is global, and changes in Danish land use and biomass production may potentially cause changes in land use in other regions globally, thereby changing the greenhouse gas emissions and ecosystem services from these regions. In this study the changes in food and feed production are marginal for all three scenarios, why any ILUC effects will be equally small and therefore not considered in the analysis.

## Method

Emission or uptake of greenhouse gases from LUC was in this study calculated with a high degree of precision, as the exact

land use is known for both the starting point in 2009 and the three scenarios. Only areas affected by the +10 mio tons study are included. The method of calculation follows the standard for such calculations as laid out by IPCC, and the input data is based on extensive agricultural statistics covering crop types, yields and fertilization. For each scenario, calculations have been made for all crops, tree species, soil type and agricultural practice. Only changes in the field or forest has been included, while changing demands for transportation or soil treatment are considered non-significant compared to the total level of emissions. Emissions associated with biomass from roadsides and weed cutting are difficult to estimate and not included. Because

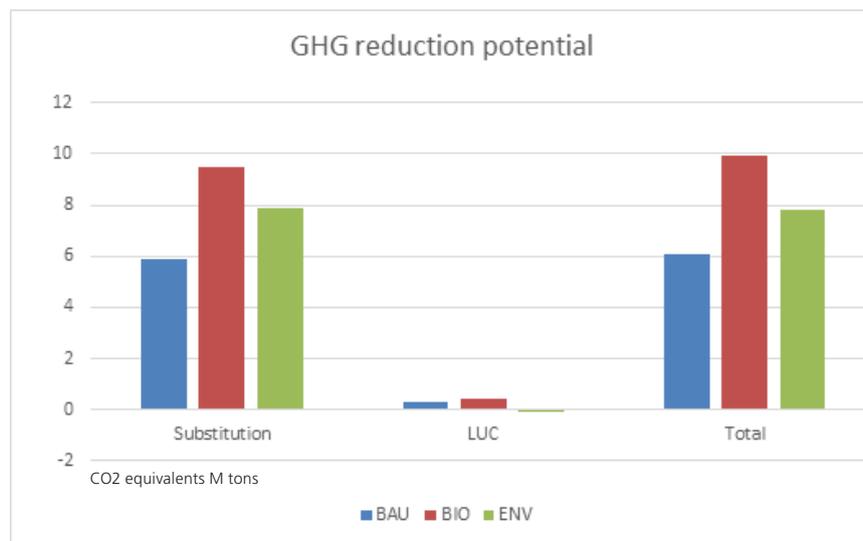


Figure 11. Reduced greenhouse gas emissions shown as CO<sub>2</sub> equivalents from either fossil fuel substitution or land use change for each scenario.

of their small extent this is believed not to change the results at a significant level. Changes in emissions of  $\text{CH}_4$  and  $\text{N}_2\text{O}$  are converted to  $\text{CO}_2$  equivalents.

The reduction in  $\text{CO}_2$  emissions from substitution is calculated on an assumption of biomass combined with a set of conversion technologies replacing fossil fuels. For each biomass type there is a given combination of energy services provided by a bio refinery sector with a focus on producing energy carriers for transportation and biogas (methane). Byproducts are also used for energy services including heat and power. Substitution effects are not calculated on the basis of largest  $\text{CO}_2$  reduction, but on basis of the energy services demand in 2020. Only the changes in biomass production compared to 2009 are included in the calculations.

The yellow and green biomass types are mainly allocated to a 2<sup>nd</sup> generation bioethanol process, with an up-front separation of protein from the green biomass. The black biomass type is converted to bio-diesel by pressing and trans-esterification. The grey biomass type is converted to biogas and the brown biomass type is combusted to heat and power.

Calculations such as these are associated with some uncertainty and the exact values from the results should be used with caution. However, the calculations provide good estimates of the greenhouse gas emissions from the different scenarios and allows for comparison between these.

## Results

The difference in emissions from land use changes between the three scenarios are mainly caused by differences in soil carbon levels and fertilizer use resulting from different crops (figure 11). The differences in substitution effects are caused by different biomass levels, their composition and the choice of conversion technologies. For soil carbon levels the largest effect can be seen during the first years after land use change, whereupon the effect diminishes with time.

The changes in greenhouse gas emissions from substitution effects are far larger than what is seen from land use change. Intensification of agriculture and forestry by itself only causes minor changes in the emissions

of greenhouse gases, whereas the application of biomass for replacement of fossil fuels has a large reduction potential.

The combined results show a large potential for reducing emissions of greenhouse gases. In a Danish context the scenarios in the +10 M tons plan could reduce the national level of greenhouse gas emissions by more than 20% (figure 12). Especially the Biomass- and Environment scenarios show large potential reductions in the order of 8-10 M tons of  $\text{CO}_2$  equivalents. For comparison the total emissions from the Danish agricultural sector by 2020 are estimated to be 10.4 M tons  $\text{CO}_2$  equivalents. However, due to regulatory practices, the greenhouse gas reductions would be assigned to sectors other than agriculture and forestry.

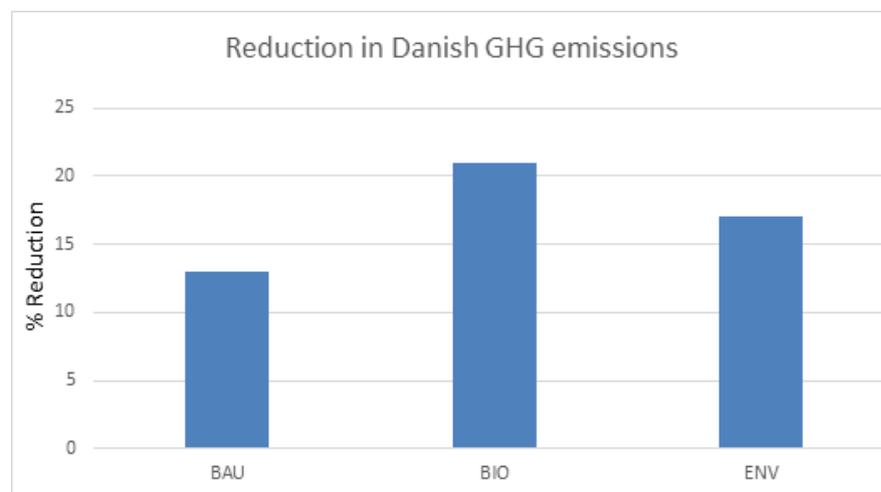


Figure 12. Estimated reduction of Danish  $\text{CO}_2$  emissions in 2020 if the scenarios are implemented.

# Cost of biomass for biorefineries

A reliable and cost efficient supply of biomass of good quality is and will be the backbone of the expansion of the bioeconomy. As stated earlier it has been shown that it is possible to produce an additional 10 million tonnes of biomass dry matter at a national level.

However, the availability and cost of biomass for the individual biorefineries will depend on the location and type of biomass to be used at the biorefinery.

To exemplify how location will affect cost “from field to biorefinery gate” two model biorefinery facility locations will be examined based on Geographical Information System (GIS) data. Available information will be field size, field location, soil quality, roads and crop composition.

A recent study has examined the possibilities and cost of a year-round supply of 150.000 tonnes biomass (DM) to a biorefinery facility. The calculations are based on a geographical area of 50.000 hectares, where the specific crop distribution for 2014 has been used for the calculations. To illustrate the influence of soil quality on costs, the calculations have been done for two representative agricultural areas with different soil types and therefore different crop compositions and yields.

One model plant was located in an area with rather poor soil quality in Southern Jutland – (“South” in Figure 13), and one in an area with better soil production conditions in the mid-part of Jutland (Middle).

When combining GIS data with yield and production cost of each soil type together with storage and transportation costs it is possible to calculate the cost of supplying the 150.000 tonnes of biomass to each model biorefinery. In both cases the necessary amount of biomass can be produced within a less than 30 km radius of each model biorefinery.

## The cost of supplying biomass

In the examples only biomass which are all-ready produced like straw from grain, maize silage, rapeseed straw, willow, whole crop, grass and beets are used.

Since a year-round supply is needed (equal to 12.500 tonnes dry matter per month), some types of biomass goes directly from field to the biorefinery while other biomass will be stored for later use.

The total cost of supplying biomass to a biorefinery is thus a combination of different crop production and harvest costs as well as transportation and storage costs.

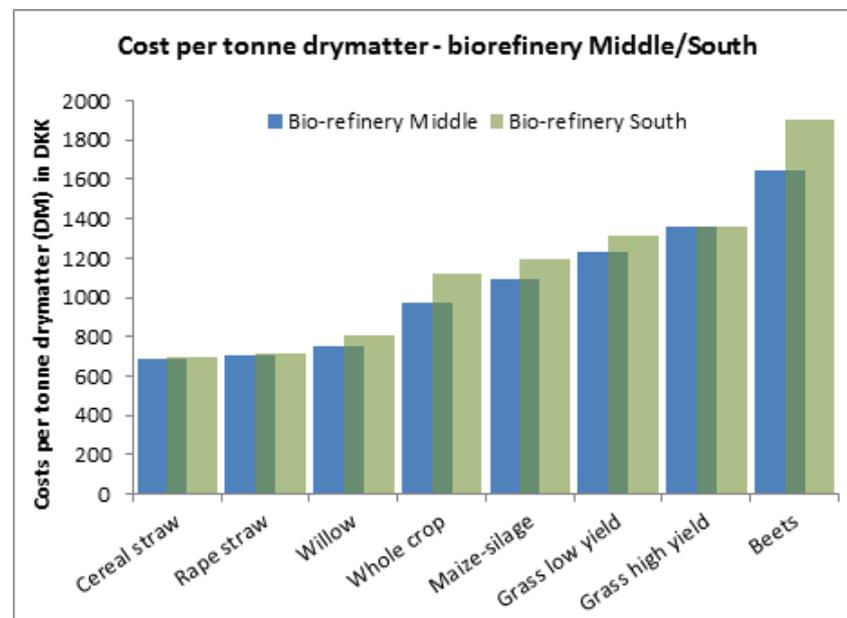


Figure 13 Supply curves showing the average cost per tonnes of drymatter biomass produced of different crops for two model bio-refineries.

Some types of biomass have lower production cost than others, especially straw and rapeseed straw as they are by-products of grain and rapeseed production. However, removing straw from the field removes some nutrients and carbon of which the value is not accounted for in the cost estimates presented.

As the cost of different biomass inputs are different, the total cost of the biomass mix will increase when demand grows within a given area, biomass with the lowest cost to be used first until demand is met. This can be shown in a supply curve (figure 13). As can be seen the biomass from straw has the lowest cost followed by willow, whole crop and maize silage. The “wet crops” like grass and beets have the highest cost. In general the “Middle”-case with good soil quality has the lowest average biomass cost.

If there are no restrictions concerning the type of biomass for the biorefinery the cheapest available mix of biomass within the 30 km radius will be used. The supply of biomass to the model bio-refineries will then consist of different types of biomass from month to month. As an example, in the “Middle”-case some months the supply is purely made up of maize silage or straw and in other months the biomass will be mixed as shown in figure 14.

### Using only by-products – Increasing the radius

In the examples the production of the lowest cost biomass inputs (straw and rapeseed straw) or other specific biomass types close to the model biorefineries is not sufficient to supply 150.000 tonnes of dry matter. If specific types of biomass are wanted it can be necessary to increase the transport distance to meet demand. At a radius of 40 km from the model biorefineries enough straw and rape straw can be found, but at higher transportation costs.

It is thus initially possible to supply biorefineries without changing or limiting the current production. When comparing soil quality to cost, the “Middle”-case with the comparatively better soil quality has the lowest cost

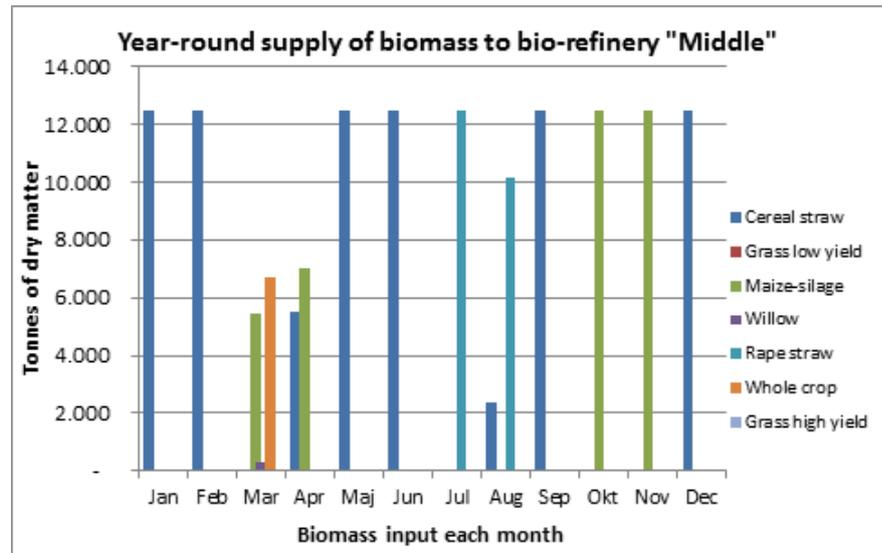


Figure 14. Year-round monthly supply of biomass exemplified for the mix of crops in the model biorefinery for the “Middle” case.

# Effect on economy and employment

Increased production of biomass from agriculture and forestry and the incorporation of hitherto unused biomass in biorefining will have consequences for economy and employment. These will be direct consequences in the affected sectors such as agriculture, forestry and biorefineries. Also there will be indirect knock-on effects from the demand by these sectors for raw materials and for inputs from other industries.

Economic assessments have been carried out for the three alternative scenarios: BAU, Biomass and Environment. Four sources of biomass are included in the calculations:

- Conversion of actual crop production; for example, changes to crop composition, use of cover crops, etc.
- Recovery of external biomass resources (road verges, water weed clearing, etc.).
- Biomass from animal manure.
- Increased production of biomass from forestry.

The economic implications for agriculture of changes in crop production have been calculated using the agricultural model *ESMERALDA* of the Institute of Food and Resource Economics, which also includes adjustments to the area of crop production not used for biorefining. The costs associated with harvesting of external biomass are based on the cost of managing permanent grasslands. For biomass in animal manure a fixed cost has been used per tonne of dry matter, for example for transport.

The costs for forestry are based on, among other things, the market price for wood-chips.

## Production costs in the primary industries

Table 3 below shows the preliminary calculations of the additional costs associated with the three scenarios in agriculture and forestry. The results are the sum of the costs of fertiliser, pesticides, energy, services, machinery and labour input (including that of the user) in the relevant production lines (mainly rape, sugar beet, energy willow, permanent grass and cereal).

Total extra production costs for agriculture and forestry are between 3.5 and 5.7 billion DKK per year, depending on the scenario. The calculations show that the costs of harvesting hitherto unused biomass resources (external biomass) such as permanent grasslands in wetland areas and road verges, water weed clearing, etc., make up a large share of the costs in all three scenarios. In the Biomass scenario, an extensive conversion of areas with cereal

and rape to sugar beet is assumed, where the costs per hectare are somewhat higher than for cereal. The Environment scenario includes an extensive conversion to grasses, where the costs per hectare are a little lower than for cereal.

## Socioeconomic consequences

The derived effects of the three scenarios on the rest of the economy have been analysed using a so-called input-output model for the Danish economy supplemented with the following assumptions:

- There is spare capacity in the rest of the economy to the extent that the demands of the biorefinery sector do not have an impact on input prices, including wage levels.
- The calculations measure the isolated effect of an increase in biomass production and refining, and therefore no associated displacement of other production.
- The income generation factor in the biorefinery sector is ignored in the analysis due to insufficient data regarding the economy (mainly labour and capital use) in the biorefinery sector.

Table 3. Production costs of biomass in the primary sectors (2011).

Billion DKK	BAU	Biomass	Environment
Conversion of agricultural crop production	0.03	0.86	-0.58
External biomass	3.08	3.76	3.20
Animal manure	0.51	0.51	0.49
Increase in biomass from forestry	0.38	0.77	0.46
Total production costs	4.00	5.70	3.57

In addition to the cost of the biomass itself, the biorefinery sector also uses a number of other raw materials and intermediate goods and services, including enzymes and water, energy and transport. The costs of refining the biomass in the biorefinery sector is estimated from a report by Bloomberg (2012) and by Larsen et al. (2008) and adjusted for development in productivity in the manufacture of enzymes, for example. The calculation of costs is therefore based on an ethanol technology and is assumed to be applicable for future plants that also produce diesel and natural gas equivalents. The biorefineries' expenditure on raw materials, semi-finished goods and services has thus been estimated at 8.5 billion DKK (for the BAU scenario) and 16 billion DKK (for the Biomass scenario) per year, while

the Environment scenario has expenditures of between 11-12 billion DKK, of which approx. 90 % is associated with domestic deliveries.

Refining the biomass specified in the three scenarios would in the future generate an increase in the rest of the economy of 14 to 26 billion DKK. In this figure we ignore displacement of existing production, for example some of the existing fossil-based production disappearing in favour of an increased export of crude oil.

The demands of the biorefineries would in addition to the production also indirectly generate employment. As Table 5 shows, an additional 12,000, 21,000 and 14,000 jobs will be generated with the three sce-

Table 4. Impact on production, billion DKK (2011)

Sector	BAU	Biomass	Environment
Agriculture, fisheries, extraction of raw materials	5.07	7.74	4.83
Industry	3.38	6.55	4.84
Energy and water supply	1.42	3.07	2.38
Building and construction	0.63	1.35	1.03
Trade, hotel and catering	0.68	1.18	0.82
Transport, postal service and telecommunications	1.06	2.22	1.69
Financial and business services	1.61	2.87	2.01
Public and personal services	0.15	0.26	0.17
Associations, culture and refuse disposal	0.11	0.21	0.15
Total	14.11	25.45	17.92



PHOTO: UFFE JØRGENSEN

narios, of which approximately 33–50 % will be in agriculture, fisheries and the extraction of raw materials (including forestry).

The feedstock requirements of the biorefineries will also have an indirect effect on income generation in the rest of the economy. Table 6 shows that the three scenarios will lead to a gross income of between 5.9 and 10.9 billion DKK. Similar to employment, the largest income generation is in agriculture, fisheries and extraction of raw materials. The relative contribution is, however, somewhat smaller than seen for employment.

The socioeconomic calculations do not include the adjustments that will take place in the rest of the economy. These adjustments can, for example, be quantified by incorporating more advanced economic models, such as general balance models where biorefineries are included on an equal footing with other sectors in the Danish economy. This will, however, require more precise data on the production technology and market for refined products than has been possible in this analysis.

As previously mentioned, the results show the isolated effects of a future biorefinery sector in Denmark. It is, for example, conceivable that biobased products will displace the production of fossil-based products. The results can therefore be perceived as gross values.

Since it has not been possible to obtain reliable data for the use of capital and labour, employment and income generation from the biorefinery sector itself have not been included. Neither has it been possible to analyse the profitability of a future biorefinery sector and its dependence on sales prices and possible subsidies.

*Table 5. Impact on employment, number of persons (2011).*

<b>Sector</b>	<b>BAU</b>	<b>Biomass</b>	<b>Environment</b>
Agriculture, fisheries, extraction of raw materials	5,978	8,897	5,448
Industry	1,842	3,558	2,623
Energy and water supply	399	857	663
Building and construction	421	863	653
Trade, hotel and catering	823	1,455	1,020
Transport, postal service and telecommunications	879	1,842	1,401
Financial and business services	1,607	2,865	2,016
Public and personal services	246	420	276
Associations, culture and refuse disposal	112	208	149
<b>Total</b>	<b>12.306</b>	<b>20.965</b>	<b>14.249</b>

*Table 6. Gross income, billion DKK (2011).*

<b>Sector</b>	<b>BAU</b>	<b>Biomass</b>	<b>Environment</b>
Agriculture, fisheries, extraction of raw materials	2.04	3.24	2.06
Industry	1.09	2.16	1.62
Energy and water supply	0.80	1.74	1.35
Building and construction	0.19	0.40	0.30
Trade, hotel and catering	0.33	0.57	0.40
Transport, postal service and telecommunications	0.43	0.61	0.69
Financial and business services	0.88	1.56	1.09
Public and personal services	0.10	0.18	0.12
Associations, culture and refuse disposal	0.06	0.11	0.08
<b>Total</b>	<b>5.92</b>	<b>10.87</b>	<b>7.71</b>

# Would such developments be acceptable to the society?

There are a number of ethical issues attached to the use and production of bio-energy that often end in simplified discussions of »for« and »against«.

It is therefore important to get a more precise picture of what the crux of the discussions is to enable a more reflective and transparent development of biomass for energy and industrial purposes.

The Danish Council of Ethics based its report from May 2012 on bioenergy, food and ethics on the four crises/challenges: energy, food, climate and nature and the impact on these from a general but not specified principle of not harming the environment. For an increased production of biomass for energy purposes this approach leads to the following reflections by the Council:

- An increased domestic production of biomass can be ethically acceptable,
  - if the volume of global food production is maintained and/or food prices do not rise (with the proviso that there is no guarantee that Danish food production will benefit the starving in the world)
  - if the consumption of animal products is reduced and the area can be expanded (with the proviso that the majority of Danish livestock production goes to export/if sections of livestock produc-

tion are moved abroad this can adversely impact animal welfare, nature and environment)

- perhaps, with the use of green technologies (including genetic modification to achieve higher yields).
- It is ethically unacceptable,
  - if the crops involved will compete with food production, or if threatened habitats are put under further pressure, or

if long-term soil fertility is threatened (through the removal of carbon in straw)

- since increased production is not the answer, the focus should instead be on reducing consumption.

As the above shows, The Danish Council of Ethics finds that a Danish production of biomass could be considered ethically responsible as long as the production is sustainable.



PHOTO: UFFE JØRGENSEN

# Actions needed to reach the target

As part of the preparation of the 10 million tonnes plan, a number of research areas/ topics were identified that combined would be able to support the target of a 10 million tonnes increase in the supply of biomass from Danish forestry and agriculture for a bioenergy and biorefinery sector.

The research and development activities could help realise the additional 10 million tonnes of biomass from agriculture and forestry for the bioenergy and biorefinery sector within a reasonable time frame. Such a activities could, of course, not stand alone but would need the support of pilot and demonstration facilities for the results to be tested at industrial level where different models of organisation can also be tested.

A number of the crops/biomasses that form the basis for the 10 million additional tonnes are not traditional sales crops and new market-oriented forms of cooperation therefore need to be in place. This is believed to be best achieved via long-term contractual relations.

Mutually binding private-public partnerships would be a useful tool for promoting this development. The Biorefinery Alliance is here a good example of a partnership where the ambition is to promote a green conversion.

The SPIR BioValue projects is another example of Public Private cooperation. And the Biobase technology platform established at Aarhus University forms a framework for research and development of production systems and technologies for refining of green biomass.

Below is a list of the most important areas and topics that should be part of future research and development activities. This may be combined in one or more cross-disciplinary initiatives. It is important to ensure, however, that sufficient resources are dedicated to understanding and developing the basic links in the biomass production so that these can subsequently be used to improve not only productivity, but also the environment.

## Agriculture

### 1. *Potential in genetic resources*

- a. Capacity to increase the straw yield in cereals through selective breeding for varieties with thicker and stronger stems
- b. New, high-yielding perennial grasses for green biomass. Tolerance to abiotic stress (temperature and water) to ensure a long growing season
- c. Optimisation of quality for storage and conversion.

### 2. *Innovative crop management systems*

- a. Potential to increase straw yield through new management strategies without compromising on grain yield (plant density, timing of nitrogen application, etc.)
- b. New crop rotations with early harvest of high-yielding cereal crops (triticale, for example) followed by cover crops in order to grow two crops in a growing season
- c. New soil amelioration products and methods to maintain soil organic carbon stocks
- d. Utilisation of C<sub>4</sub> crops, either as annual crops in combination with C<sub>3</sub> crops in the winter or as perennial crops
- e. Maintenance of high productivity of long-term grass production.

### 3. *New harvesting and storage technologies*

- a. Collection of grain chaff and leaves currently not utilised
- b. Earlier harvest of cereal, airtight storage and importance for feed value of grain and straw yield
- c. Silaging of moist biomass and effect on convertibility
- d. Pre-treatment of green biomass before or after storage.

### 4. *Land-based Life Cycle Assessment (LCA)*

- a. Analysis of the environmental profile of new cropping systems per unit product and unit area
- b. Mapping of regional differences in the resilience and sensitivity of soils
- c. Effect of different types of land use in catchment areas of biorefineries (sustainability analysis)
- d. Direct and indirect effects on pollution, biodiversity, greenhouse gas emissions of energy consumption and other non-renewable resources (LCA).



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### 5. *Socioeconomic and ethical aspects*

- a. Economic optimisation of primary production and adjustment in the agricultural sector to an increased production of biomass for use in biorefineries
- b. Adaptation and integration of modelling system for analysing consequences for the sector and for socioeconomics of development scenarios for a biobased economy
- c. Embedment of an actual biorefinery sector in a socioeconomic sector model
- d. Grasp of sustainability challenges
  - underlying values and possible conflicts when balancing considerations
- e. Handling of sustainability challenges
  - significance of governance strategies in a national and international context.

## Forestry

### 6. Forestry – breeding and production

- a. Breeding of forest tree species for productivity and quality in response to new demand patterns.

### 7. Management systems – operational and socioeconomic analyses

- a. Development and implementation of new management systems for a larger mobilisation of wood biomass
- b. Optimisation of operational and socioeconomic aspects of new management systems.

### 8. Resources – potentials and climate impact

- a. Analyses of potentials for a larger mobilisation of biomass from forests
- b. Analysis of climate trade-offs between the storage of carbon in forests and the displacement of fossil carbon, including LCA – at national and global level
- c. Inventory of non-forest timber volume and analysis of production and application potential
- d. Analysis of sustainability and long-term productivity at an increased biomass production
- e. Analysis and documentation of environmental impact - including on biodiversity of increased biomass production.



PHOTO: LEA VIG MCKINNEY

# Colophon

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The + 10 million tonnes study. Increasing the sustainable production of biomass for biorefineries. Updated edition 2016.

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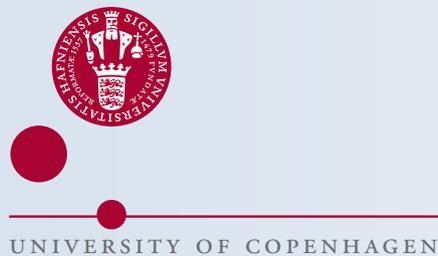
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