The + 10 million tonnes study
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THE + 10 MILLION TONNES STUDY

Increasing the sustainable production of biomass for biorefineries
The need to create sustainable solutions in the energy sector has led scientists at the University of Copenhagen, Aarhus University and R&D staff from DONG Energy to set up an agreement on joint research and education initiatives in bioenergy. An important part of the collaboration is a study on how we sustainably can increase the production of biomass without undermining food and animal feed production. The study is published here under the title »The + 10 million tonnes study«, and the report 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 realise this, further research and development is required, particularly within agriculture and forestry, but also within the biological and chemical conversion of biomass.

The initiative supports the BioRefining Alliance which brings together Danish companies, public authorities and organisations with world-leading know-how and technology within biorefining. The project is part of the collaboration agreement on research and education in bioenergy, which University of Copenhagen, Aarhus University and DONG Energy set up in December 2011.
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 this done in practice and what it actually requires, not just for the Danish economy and energy supply, but also for environment and nature? Is it possible for Danish agriculture and forestry to produce sufficient biomass for a new bio-refinery sector, without negative impacts on the environment or food production. Also what would be the consequences of such a development for economic growth and employment?

These questions have formed 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 in Denmark. This is feasible because:

- Harvest of biomass from approx. 70,000 ha of wetland areas and in this way also contributing to a more benign cropping systems.
- Increased recovery of biomass if we also expect to achieve large environmental benefits. Nitrates leaching from annual cropping systems is for example an important which production systems are selected for growing large quantities of biomass.
- Harvest of biomass from approx. 70,000 ha of wetland areas and in this way also improving biodiversity from stemming the encroachment of nettles and willow. Bio-mass 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 before 2020.

For forestry, the extra 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 a 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 bio-refining 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 Commissioner'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, farmers, 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. Nitrates leaching from annual cropping systems is for example approximately three times higher than from perennial cropping systems.

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 and increase biodiversity in Denmark. This is feasible because:

- 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 nitrates leaching from agricultural production 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.
- Increased 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 improving biodiversity from stemming the encroachment of nettles and willow. Biomass and nutrients can likewise be harvested from approx. 7,000 ha of road verges, also here contributing to a more varied flora.

The adoption of the technologies and strategies are implemented before 2020.

For our results show that it is feasible to make significant environmental improvements. The leaching of nitrates from agricultural soil can be reduced by approximately 23,000 tonnes and biodiveristy will benefit in the environment-optimised scenario.

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.

The production from a Danish bio-refinery sector would for the 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 constitute an additional 5% of our petrol and diesel consumption. The biomass production in the scenarios is based on the expected co-products from the bio-refining process is animal feed, and conversion and employment.

The results also show that it is feasible to make significant environmental improvements. The leaching of nitrates 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 bio-refinery 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 background for the investigation was the question on whether it would be possible for Danish agriculture and forestry by the creation of conservation wood stations with new species obviously has a much longer horizon.

The proposed scenarios involve a 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 bio-refining process is animal feed, and conversion and employment.

The biomass production in the scenarios corresponds more or less to the Climate Commissioner'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, farmers, 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. Nitrates leaching from annual cropping systems is for example approximately three times higher than from perennial cropping systems.
Land use

The Danish landscape is dominated by agriculture (Figure 1). Of its 43,100 km² land area, 26,000 km² is farmland, i.e. 62 % of the area. Woodland covers approx. 5,800 km² (14 %), of which the majority is managed. The remaining approx. 11,300 km² (26 %) is used 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 production of about 20 million tonnes. The majority of this is made up of cereals, grass and forage plus 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 certain 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 hedges, 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 hedges 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.

Table 2. Production and utilisation of industrial waste fractions in Denmark in 2009. Based on data from the Danish Environmental Protection Agency.

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

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.
Biomass is mainly made up 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 degradation fungi. Biomass also contains smaller quantities of proteins and oils, but these vary between the different kinds of biomass, 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, the conversion process will produce pure heat. If the oxygen is removed, the biomass will produce 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. The gas is currently mainly 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 mostly used together with other conversion methods and leads to a chemical conversion 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 process 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 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. Biologically, the 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 so wished.

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 destroyed with incineration, gasification or digestion. In the biochemical conversion process and 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. Biologically, the 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 so wished.

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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 environmentally sensitive or valuable nature areas. It is, for example, planned to ban crops from a 10-m wide buffer zone along water courses.

Another important aspect is the restriction 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 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 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 practice. Particularly three aspects would appear to be able to affect the production potential of agriculture:

- Crop diversification. Farms above a certain size must grow at least three different crops. None of these crops should be grown on less than 5 % of the area and the main crops should not be grown on more than 70 % of the area.
- Environmental protection. Farmers must dedicate at least 7 % of their farm area, except for permanent grassland, to environmentally protected areas, which can include fallow land, landscape features and buffer zones.
- Continuation of permanent pastures at farm level. Farmers must continue the permanent pastures that they have officially recorded as such in their 2014 subsidy application.

Forestry is not expected to be affected by the EU policy to the same extent, but forestry will be affected by the increasing demand for forest biomass.
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 destined for bio-refining that can 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 approximately 9 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 storing it in airtight silos. That straw has not been a primary product of cereal production is reflected in the harvesting process jettisoning most of the stalk in the autumn and is therefore able to utilise the 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 C₄ photosynthesis in the summer and a cold-tolerant C₃ 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 bio-refining of this twofold increase in production also includes animal feed products andSilka 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 scena-
or, 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 va-
tility selection.

In the biomass-optimised scenario we per-
form a number of optimisations to increase
the biomass quantity and in the environ-
ment-optimised scenario a number of addi-
tional measures are implemented to pro-
mote sustainability in the form of, for
example, reduced nitrate leaching, increased
soil carbon storage and biodiversity.

A brief overview of the features of the indi-
vidual scenarios is set out below. In none of
the cases has the entire co-product resource
utilisation in year 2009. In the business-
as-usual scenario, we assume an increased
utilisation in year 2020 with the production
and utilisation in year 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
above 35 % – instead perennial energy
crops.

The gains achieved from genetic im-
provement before the EU common agricul-
tural 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.

Increased mobilisation of wood biomass
but growth exceeds harvest.

In the biomass-optimised scenario we per-
form a number of optimisations to increase
the biomass quantity and in the environ-
ment-optimised scenario a number of addi-
tional measures are implemented to pro-
mote sustainability in the form of, for
example, reduced nitrate leaching, increased
soil carbon storage and biodiversity.

Business-As-Usual (BAU)

• No changes to species or variety or har-
vesting technology but the residual bio-
mass (straw, slurry and meadow grass)
are utilised.

• Deciduous woodland is regenerated with
• Perennial energy crops replacing beet (by
2020 expected yield is 15 t/ha with later
yields projected to reach those of beet).

• No straw removal from areas with criti-
cally low soil carbon content.

• Increase in area with cover crops
(81,000 ha).

• 1900 ha afforestation per year.

• Extensive use of faster-growing tree spe-
cies such as nurse trees, for example in
mixed woodland and new plantings.

• The gains achieved from genetic im-
provements of trees are utilised.

• Coniferous forests are regenerated with
conifers and deciduous forests with 50 %
broadscale, 50 % conifers.

• Greatly increased recovery to wood bio-
mass of roughly the same size as growth.

Environment-optimised (Environment)

Same as Biomass-optimised, except for:

• No straw removal from areas with criti-
cally low soil carbon content.

• Increase in area with cover crops
(81,000 ha).

• 1900 ha afforestation per year.

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cies such as nurse trees, for example in
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• Coniferous forests are regenerated with
conifers and deciduous forests with 50 %
broadleaf, 50 % conifers.

• Greatly increased recovery to wood bio-
mass of roughly the same size as growth.

Biomass-optimised (Biomass)

• Conversion to cereal species producing
15 % more straw.

• Increased recovery of straw (15 %) via
modification of harvesting technology.

• Oilsed 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 con-
verted 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 spe-
cies such as nurse trees, for example in
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• Greatly increased recovery to wood bio-
mass of roughly the same size as growth.
An additional 10 million tonnes biomass can be produced

The scenarios (Figure 5) show that a heavier exploitation of the existing biomass produc-
tion (BAU scenario) can yield approximately 4 million tonnes of dry matter per year in
addition to the almost 4 million tonnes al-
ready recovered in agriculture and forestry.

For agriculture, the BAU scenario shows that
an additional 10 million tonnes biomass can
be found through an improved recovery tech-
nique for straw, a change towards more straw-rich varieties,
and finally through new cropping systems.

For forestry, the BAU scenario shows that
an additional 4 million tonnes of dry matter in
addition to the almost 4 million tonnes al-
ready recovered in agriculture and forestry.

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 imple-
mentation of a large-scale transition to
crop changes in agriculture and forestry.

For agriculture, the BAU scenario shows that
an additional 0.8 million tonnes dry matter per year can be collected by 2020, corre-
sponding roughly to a doubling of the for-
est biomass. By implementing a number of optimisa-
tions (Biomass), biomass from agri-
forestry can likely contribute an additional
0.75 million tonnes dry matter. This is pri-
marily through an increased mobilisation
of relatively simple measures such as differ-
cultivation systems. In the Environ-
ent scenario the biomass potential is ap-
prox. 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 divi-
ded into five main categories, each de-
ned for specific energy technologies (Figure 6).
Yellow biomass is straw from cereal
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 verg-
es and water weed clearings) draw up sce-
narios for developments in the production
of biomass from waste or from areas other
than from agriculture and forestry.

The largest potential is found in green bio-
matter (grass, beet, and the like), which has
a high water content suitable for biological
storage techniques for large quantities of
biomass. Straw is mainly burnt, but a small
amount is used in biorefining in a biologi-
cal process. The utilisation of yellow bio-
mass may be improved, and with the use
can via the choice of crops be changed to
the brown biomass category (willow, pop-
lar or other woody plants), which is better
suited to thermochemical conversion. An-
other 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
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The scenarios (Figure 5) show that a heavier
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and finally through new cropping systems.

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crop changes in agriculture and forestry.

For agriculture, the BAU scenario shows that
an additional 0.8 million tonnes dry matter per year can be collected by 2020, corre-
sponding roughly to a doubling of the for-
est biomass. By implementing a number of optimisa-
tions (Biomass), biomass from agri-
forestry can likely contribute an additional
0.75 million tonnes dry matter. This is pri-
marily through an increased mobilisation
of relatively simple measures such as differ-
cultivation systems. In the Environ-
ment scenario the biomass potential is ap-
prox. 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 divi-
ded into five main categories, each de-
ned for specific energy technologies (Figure 6).
Yellow biomass is straw from cereal
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 verg-
es and water weed clearings) draw up sce-
narios for developments in the production
of biomass from waste or from areas other
than from agriculture and forestry.

The largest potential is found in green bio-
matter (grass, beet, and the like), which has
a high water content suitable for biological
storage techniques for large quantities of
biomass. Straw is mainly burnt, but a small
amount is used in biorefining in a biologi-
cal process. The utilisation of yellow bio-
mass may be improved, and with the use
of relatively simple measures such as differ-
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conversion to biogas.
Implementation of the scenarios will have implications for how the 2.7 million ha of farmland is used (Figure 7). By 2020, the farmed area is expected to be diminished to 2.6 million ha, as land continues to be taken over by roads, housing and forests. In 2009, approx. 0.24 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 production, 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 bio refineries 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 permanent grass on wetland soils – is, however, currently extensively farmed.

The bio refineries, 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 a comparable feed production to what is lost from the smaller 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 in 2100, while the Environment scenario would produce 1.7 million tonnes and the BAU scenario 0.95 million tonnes per year (Figure 8).

Figure 7. Land area dedicated to biomass production in Danish agriculture in 2009 and 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.

Figure 8. Development in the amount of wood biomass available for biorefineries from 2000 to 2100 in the three scenarios.
Production and utilisation of biomass for bioenergy 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 the Water Framework Directive. The Environment scenario can help improve the nitrogen per year (Table 2). This compares with a figure for total nitrate leaching of between 7,000 and 23,000 tonnes nitrogen per year (Table 2). This compares with a figure for total nitrate leaching of between 7,000 and 23,000 tonnes nitrogen per year. This compares with a figure for total nitrate leaching of between 7,000 and 23,000 tonnes nitrogen per year. This compares with a figure for total nitrate leaching of between 7,000 and 23,000 tonnes nitrogen per year.

Selection and rejection are important
There are many other environmental impacts associated with agricultural productivity, 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, partly because the soil is not ploughed every year. Pesticide use is high in sugar beet and rapeseed 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.

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

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

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 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. earthworm) prefer areas where the soil is less disturbed. Rarer plant and animal species are primarily found in dedicated nature conservation 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 composi-

tion 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 support-
ing 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 biodi-

versity in the forests. The rate of afforesta-
tion 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 biodiver-
sity generally.

The Biomass scenario assumes that higher priority is given to the growing of coniferous rather than deciduous trees. Such a develop-

ment of the species composition of the forests will on the whole have a negative impact on biodiversity.
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 feed 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$^3$ per ha, corresponding to 68 tonnes carbon per ha. This is a large quantity of biomass compared to the European average of 107 m$^3$ per ha, but more can be achieved. It is relatively easy to increase the carbon stored in forests by ceasing felling and utilisation 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 scenario 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.

Figure 9. Amount of carbon stored in living forest biomass in the three scenarios.
Effect on economy and employment

Increased production of biomass from agriculture and forestry and the incorporation of hitherto unused biomass in biofueling will have consequences for economy and employment. These will be direct consequences in the affected sectors such as agriculture, forestry and biofuels. 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: cover crops, crop production, forestry, and biofuels. The costs for forestry are based on, among other things, the market price for woodchips.

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 willow, 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 biofuel sector is ignored in the analysis due to insufficient data regarding the economy (mainly labour and capital use) in the biofuel sector.

In addition to 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 and 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 scenarios, 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.

Table 3. Production costs of biomass in the primary sectors.

<table>
<thead>
<tr>
<th>Billion DKK</th>
<th>BAU</th>
<th>Biomass</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion of agricultural crop production</td>
<td>0.03</td>
<td>0.86</td>
<td>-0.58</td>
</tr>
<tr>
<td>External biomass</td>
<td>3.08</td>
<td>3.76</td>
<td>3.20</td>
</tr>
<tr>
<td>Animal manure</td>
<td>0.51</td>
<td>0.51</td>
<td>0.49</td>
</tr>
<tr>
<td>Increase in biomass from forestry</td>
<td>0.38</td>
<td>0.77</td>
<td>0.46</td>
</tr>
<tr>
<td>Total production costs</td>
<td>4.00</td>
<td>5.70</td>
<td>3.57</td>
</tr>
</tbody>
</table>

Table 4. Impact on production, billion DKK.

<table>
<thead>
<tr>
<th>Sector</th>
<th>BAU</th>
<th>Biomass</th>
<th>Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture, fisheries, extraction of raw materials</td>
<td>5.07</td>
<td>7.74</td>
<td>4.83</td>
</tr>
<tr>
<td>Industry</td>
<td>3.38</td>
<td>6.55</td>
<td>4.84</td>
</tr>
<tr>
<td>Energy and water supply</td>
<td>1.42</td>
<td>3.07</td>
<td>2.38</td>
</tr>
<tr>
<td>Building and construction</td>
<td>0.63</td>
<td>1.35</td>
<td>1.03</td>
</tr>
<tr>
<td>Trade, hotel and catering</td>
<td>0.68</td>
<td>1.18</td>
<td>0.82</td>
</tr>
<tr>
<td>Transport, postal service and telecommunications</td>
<td>1.06</td>
<td>2.22</td>
<td>1.69</td>
</tr>
<tr>
<td>Financial and business services</td>
<td>1.61</td>
<td>2.87</td>
<td>2.01</td>
</tr>
<tr>
<td>Public and personal services</td>
<td>0.15</td>
<td>0.26</td>
<td>0.17</td>
</tr>
<tr>
<td>Associations, culture and refuse disposal</td>
<td>0.11</td>
<td>0.21</td>
<td>0.15</td>
</tr>
<tr>
<td>Total</td>
<td>14.11</td>
<td>25.45</td>
<td>17.92</td>
</tr>
</tbody>
</table>
There are a number of ethical issues attached to the use and production of bioenergy 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 production 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.

Would such developments be acceptable to the society?

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 bio refineries 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 bio refinery 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 bio refinery sector itself has not been included. Neither has it been possible to analyse the profitability of a future bio refinery sector and its dependence on sales prices and possible subsidies.
Actions needed to reach the target

A number of areas have been identified where initiatives will be required to support a larger supply of biomass.

Research requirements for 10 million tonnes plan

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 bio-mass from Danish forestry and agriculture for a bioenergy and biorefinery sector. The research and development programme 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 programme could, of course, not stand alone but would need the support of pilot and demonstration facilities for 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 that ensure supply inputs and outputs for both producer (agriculture) and buyer (biorefinery sector). This is believed best achieved via long-term contractual relations.

Neither industry nor agriculture is interested in a large change to production and the construction of biorefineries without a solid market for the biorefined products. An increased mobilisation of biomass from forestry could be implemented within a short time scale, while the breeding and planting of different tree species obviously takes a longer time. A political strategy is needed that has clear targets for the development of a biobased economy and a coordinated use of appropriate grants and subsidies to guarantee the development.

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. 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 opportunities are dedicated to understanding and developing the basic links in the biomass production and conversion so that these can subsequently be used to improve not only productivity, but also the environment. The optimal time frame and coordination of individual research requirements are shown in Figure 10. Estimated funding needed for research is in the order of 90-120 million DKK.

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**Agriculture**

1. Potential to increase straw yield through new management strategies without compromising on grain yield (plant density, timing of nitrogen application, etc.)
2. 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
3. New soil amelioration products and methods to maintain soil organic carbon stocks
4. Utilisation of C4 crops, either as annual crops in combination with C3 crops in the winter or as perennial crops
5. Maintenance of high productivity of long-term grass production
6. Forage yield and production in silvicultural mixtures
7. 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
8. 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.)
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   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 C4 crops, either as annual crops in combination with C3 crops in the winter or as perennial crops
   e. Maintenance of high productivity of long-term grass production
9. 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. Slagging of moist biomass and effect on convertibility
   d. Pre-treatment of green biomass before or after storage
10. Land-based LCA analysis
   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

**Forest**

1. Land-based LCA analyses
2. Resource – potential and limitations
3. Innovative dry-milling systems
4. New and improved genetics
5. Management systems in silvicultural mixtures
6. Pre-treatment of green biomass before storage
7. Estimation of funding needed for research in the order of 90-120 million DKK

**Figure 10.** Timeline for the initiation and implementation of the research activities and results required to ensure that the targets in the 10 million tonnes plan can be achieved in time and in a sustainable manner.
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).

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
b. Optimisation of operational and socioeconomic aspects of new management systems
c. Analysis and documentation of environmental impact - including on biodiversity of increased biomass production.

d. Analysis of operational and socioeconomic aspects of new management systems.

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

Political measures
It is important that there are clear political signals and preferably a clear political strategy that sets targets for the establishment of a bio-based society.
• Tailored subsidy programmes.
• Support for the development of markets

Organisation and demonstration
An organisation for all stakeholders in the bio-value chain needs to be set up to provide access to pilot and demonstration facilities.

• Tailored subsidy programmes.
• Support for the development of markets

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.

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Prinfo Aalborg