Danish agricultural biomass production and utilization in 2030

Advisory memorandum from DCA – Danish Centre for Food and Agriculture

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Data sheet

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Contents

1 Preface

This memorandum is one out of more background memorandums from the project "Effekter ved fremtidig arealanvendelse og alternativ anvendelse af biomasse", which was ordered by the Ministry of Food, Agriculture and Fisheries. The request was based on the acknowledgement of the large impact of the current utilization of land and biomass resources for Denmark's CO_2-emissions.

The Danish Council on Climate Change in their report "Retning og tiltag for de næste ti års klimaindsats i Danmark" (2020) describes a land-use related CO_2 reduction potential of 1.4 M tonnes from *reduction* of agricultural land-use and of 0.4 M tonnes from *changes* in agricultural land-use on 100,000 ha. To achieve these reductions, there is a need to improve the existing regulations for land use change or set aside, so that they can play a larger role, and to achieve more knowledge on emission factors and land-use changes.

Furthermore, there is need for knowledge on what can preferably be grown on the land that is not permanently set aside or rewetted – is it forest, grassland or other biomass crops that are better, seen from the combined considerations for climate, environment, biodiversity, and businesses? In addition, the possible uses of the biomass produced within the bioeconomy needs further investigation.

The following organisations were invited to participate in two webinars to discuss the aims of the projects as well as the proposed scenario set-ups and preconditions: SEGES, Landbrug & Fødevarer, Bæredygtigt Landbrug, DN, ARLA, DLG, Danish Crown, Energistyrelsen, Dansk Skovforening, Danske halmleverandører, Biogas Danmark, Dansk fiskeri, Dansk Akvakultur, Musholm Laks, WWF, DTU Aqua, Frøavlerforeningen, SDU Kemi-, Bio- og Miljøteknologi, DAKOFA, DAKOFO, Sukkerroedyrkerne, Danske Maskinstationer og Entreprenører, Drivkraft Danmark, AAU Kemi og Biovidenskab, DI fødevarer, 3F, Teknologisk Institut, Rådet for Grøn Omstilling, Danish Agro, Food & Biocluster DK, DI Bioenergi, Ørsted, Miljø- og Fødevareministeriet, Klima-, Energi- og Forsyningsministeriet, Danish Marine Proteins, Vestjyllands Andel, Dansk Miljøteknologi, Novozymes, Novo, Bio2Oil and Daka.

2 The three main scenarios for agricultural land use

This analysis compares three different land-use scenarios in 2030, and the potential production and availability of biomass for biorefining for each of them. In the business as usual (**BAU) scenario**, an increased utilization of the available resources of e.g. straw, rapeseed oil and slurry is assumed, but no larger changes in cropping systems, harvesting techniques or variety selection is foreseen. The BAU scenario is compared to a **biomass scenario** that is optimized for biomass quantity and an **extensification scenario** with a lower production intensity and more land set-aside for optimized nature and biodiversity. In these two optimized scenarios, large areas are converted into perennial grasslands with positive effects on climate and environment, compared to BAU, such as increased carbon storage in soil and reduced nitrate leaching to surface waters. In the BAU scenario, only initiatives that are started and legislation that had been approved by June 2021 are included, while policy targets on climate and environment are not. For details on assumptions and calculations of biomass production in the scenarios is referred to background material (Mortensen and Jørgensen, 2022).

2.1 Business As Usual scenario 2030

1. Historical increase in crop yield and feed efficiency, and reduction in farmed area due to infrastructure and urbanization.
2. Increased utilization of residual biomass from straw and animal manure.
3. The existing production of rapeseed oil is used 100% for biorefining.
4. On organic soils, approx. 15,000 ha are rewetted with no harvest of biomass
5. The increase in organic farmed area is based on the historical trend from 2005-2015 (4,900 ha/year).
6. Afforestation of 1,900 ha per year.

2.2 Biomass scenario 2030

1. Development in crop yield, feed efficiency, reduction in farmed area and increase in organic farming as in BAU.
2. Conversion to cereal and rapeseed varieties with a 15% increase in straw.
3. Alternative harvesting technology with a 15% increase in straw recovery.
4. On organic soils, approx. 50,000 ha are rewetted and converted into:
    a. 30% natural succession and extensive grazing.

    b. 35% harvest of flooding tolerant grasses (driest areas)

    c. 35% harvest of wetland species such as cattail and common reed (wettest areas).

    d. Fertilization with N and K is allowed on the driest harvested areas to maximize removal of phosphorous.

5. On soils that are sensitive to leaching of nitrate to surface waters, approx. 319,000 ha of annual crops (cereal, maize and rapeseed) are converted to sugar beets (44,000 ha) and grass/clover (275,000 ha).

6. On loamy soils with a low carbon to clay ratio, approx. 99,000 ha of annual crops (cereal, maize and rapeseed) are converted into grass/clover, facilitating an increase in soil carbon storage.

7. On sandy soils sensitive to leaching of pesticides to groundwater reservoirs, approx. 17,000 ha of annual crops (cereal, maize and rapeseed) are converted into grass/clover.

8. Cover crops are harvested on approx. 198,000 ha. Mixtures including N_2-fixating species are allowed in order for the system to self-regulate N-availability.

9. Leaves from the existing area of sugar beets are harvested (approx. 31,000 ha).

10. Biomass cuttings from road verges and watercourse clearings are utilized.

11. Optimized manure handling (quick removal and cooling) is assumed to increase the total manure available by 7.5% of the total dry matter (DM).

12. Afforestation of 5,600 ha per year. Fast-growing coniferous species.

2.3 Extensification scenario 2030

1. Development in crop yield, feed efficiency and reduction in farmed area as in BAU.

2. Increase in organically farmed area by 100% compared to 2018 (23,250 ha/year). A large part of the new organic farming area is assumed to be on the new grasslands on nitrate sensitive soils.

3. Conversion to cereal and rapeseed varieties with a 15% increase in straw.

4. Alternative harvesting technology with a 15% increase in straw recovery.

5. On organic soils, approx. 100,000 ha are rewetted and converted into:

    a. 70% natural succession and extensive grazing.

    b. 10% harvest of natural vegetation without fertilization.

    c. 10% harvest of flooding tolerant grasses (driest areas)

   d. 10% harvest of wetland species such as cattail and common reed (wettest areas).

   e. Fertilization only with K is allowed on the driest harvested areas to maximize removal of phosphorous.

6. On soils that are sensitive to leaching of nitrate to surface waters, approx. 247,000 ha of annual crops (cereal, maize and rapeseed) are converted to grass/clover with a reduced fertilization.

7. On loamy soils with a low carbon to clay ratio, approx. 91,000 ha of annual crops (cereal, maize and rapeseed) are converted into grass/clover, facilitating an increase in soil carbon storage (80% of the area with fertilization at current N-norms and 20 % with reduced fertilization).

8. On sandy soils sensitive to leaching of pesticides to groundwater reservoirs, approx. 17,000 ha of annual crops (cereal, maize and rapeseed) are converted into 50% grass/clover for biorefining, and 50% natural succession and extensive grazing.

9. Cover crops are harvested on approx. 205,000 ha. Mixtures including N_2-fixating species are allowed in order for the system to self-regulate N-availability.

10. Leaves from the existing area of sugar beets are harvested (approx. 31,000 ha).

11. Biomass cuttings from road verges and watercourse clearings are utilized.

12. Optimized manure handling (quick removal and cooling) is assumed to increase the total manure available by 7.5% of the total dry matter (DM).

13. Afforestation of 5,600 ha per year. 50% mixed deciduous species and 50% natural succession.

3 Sub-scenarios with changes in the animal production

While animal production and feed demand is kept stable in the main scenarios, two sub-scenarios with a changed animal production are analyzed within the biomass and extensification scenarios. This is done, acknowledging the large biomass use for feed purposes, and the impact of the animal production on global climate change. Thus, sub-scenarios with an overall 20% decrease in the national animal production in 2030 are analyzed for the two main scenarios, resulting in a lower fodder demand, manure production and use of straw for animal purposes. Similarly, sub-scenarios with a 20% increase in animal production for 2030 are analyzed for the two main scenarios, resulting in an increase in domestic production of fodder and production of manure available for biogas, while the increased use of straw for animals reduces the amount of available straw for biorefining. The global animal production is expected to increase in the coming decades with consequences for the global climate and environment. An increased animal production in Denmark will increase the Danish GHG emissions from animal production, but could potentially lower the relative global GHG emissions of animal production under the precondition that a less climate-efficient production is offset elsewhere.

The sub-scenarios with changed animal production are assumed to affect the import/export balance, while the areas converted for new crops for biorefining are generally kept the same as in the main scenarios. The only exception is an area of approx. 160,000 ha with roughage crops (20% of the total area with roughage crops) that are converted into grass/clover for biorefinery in the biomass scenario with reduced animal production. In the extensification scenario, this area is set-aside as natural succession and extensive grazing. In the scenarios with increased animal production, the increased demand for roughage is assumed to be fulfilled by the fiber-fraction of the biorefining processes, while the increased demand for grain and rapeseed is adjusted via import. The new production of grass protein is substituting soy import, and in the extensification scenario with reduced animal production the excess grass protein is exported as feed. Alternatively, the excess area due to lower animal production in Denmark may be utilized in many other ways. Instead of producing grass protein to export as animal feed, a share of this area could be used for producing refined green proteins for human consumption, or for a production of protein-rich vegetables for direct human consumption.

4 Biomass production in 2030 from agriculture

The BAU-scenario for 2030 results in an increase of approx. 4.5 million tonnes in biomass dry matter (DM) production (Figure 1), by increased utilization of already known sources and technologies. This is compared to the baseline, calculated as a mean from 2015 to 2019. The largest component is heavy expansion in the utilization of animal manure (e.g. for biogas production).

In the biomass and the extensification scenarios, the conversion of large areas with cereals, rapeseed and maize into crops for biorefining, results in a deficiency in grain feed production. Furthermore, in the scenarios with a 20% increase in animal production, an overall 20% increase in both roughage and concentrate feed is assumed. Thus, from the products of biorefining we have subtracted an estimated share of the fiber fraction to substitute the share of roughage crops that are lacking in these scenarios, before calculating how much fiber is available for other purposes. In most of the scenarios, the entire production of high-value grass protein from biorefining is used for substituting soy import. Only in the biomass scenario with 20% reduction in animal production, a part of the grass protein is in excess after all soy import is substituted. The entire brown juice fraction from biorefining is available for other purposes such as biogas, with the digestate being recycled as fertilizer.

The biomass scenario for 2030 results in an increase of close to 11 million tonnes of biomass DM compared to the baseline, with a potential increase of 13 million tonnes compared to the baseline if the animal production is reduced by 20%, where some of the roughage area is turned into grass/clover for biorefining. The biomass scenario with 20% increase in the animal production results in a lower increase of approx. 10 million tonnes compared to baseline.

The extensification scenario for 2030 results in an increase of more than 8 million tonnes biomass DM compared to the baseline. If animal production is reduced by 20%, biomass availability is slightly lower than 8 million tonnes DM due to a lower quantity of manure available, while areas not needed for production of roughage are set aside for natural succession and extensive grazing instead of being used for crops for biorefining. If animal production is increased by 20% in the extensification scenario, the biomass production available for biorefining is slightly less than 7.5 million tonnes DM, the lowest number of the 2030-scenarios except for BAU. This difference compared to the other extensification scenarios is mainly due to a high use of the fiber fraction as animal feed, that is not compensated for by a higher manure production.

The biomass production in the two scenarios with increased animal production is still relatively high, and comparable with the other scenarios, which is sustained by the assumption of an increase in grain import in these scenarios.

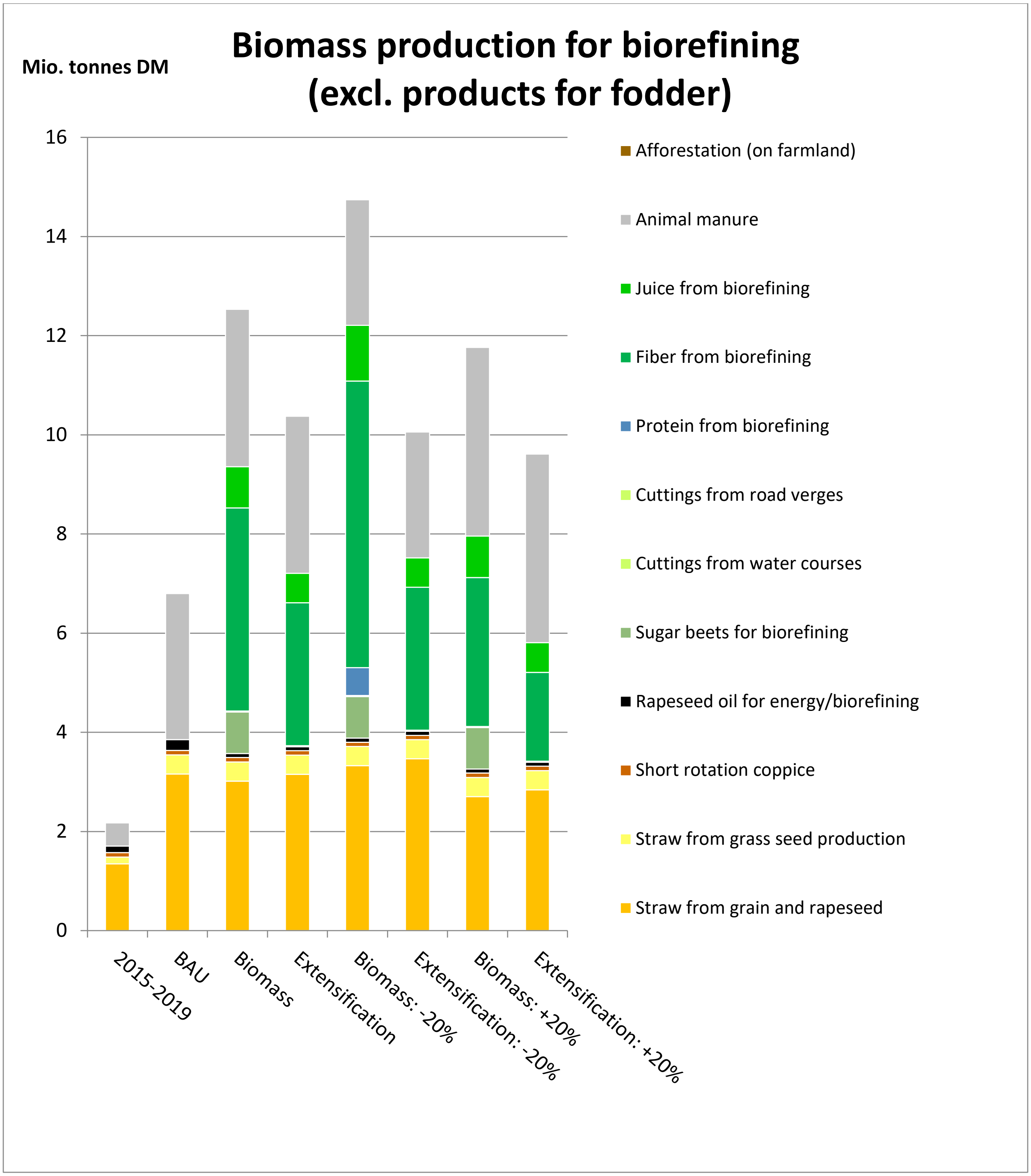

Figure 1: Potential biomass production (million tonnes DM) for 2030-scenarios of Danish agriculture. BAU = Business-As-Usual. " -/+20%" = scenarios with a 20% reduction/increase in Danish animal production. The required quantity of fiber from biorefining to substitute roughage crops from areas converted into biomass production is subtracted from these values.

5 Biomass types and discussion points

The potential production of biomass can be divided into five main categories characterized by origin and usability for energy purposes and biorefining (Figure 2). Green biomass is the main driver of differences between the scenarios. This is due to significant differences in the size of the area that is converted into grass/clover for biorefining and differences in yield between the biomass and extensification scenarios. Furthermore, the share of the fiber fraction that is needed to substitute roughage varies significantly in the scenarios due to changes in animal production.

Yellow biomass is straw from cereal and rapeseed production as well as from grass seed production, and is relatively stable between the 2030-scenarios. A 15% increase in removal of straw may have a negative impact on the soil carbon stocks. However, there is a potential of returning biochar from pyrolysis of e.g. straw to agricultural soils. This may be especially relevant on the loamy soils where there is a low content of soil C and on sandy soils where biochar may also have a positive effect on soil fertility and water holding capacity.

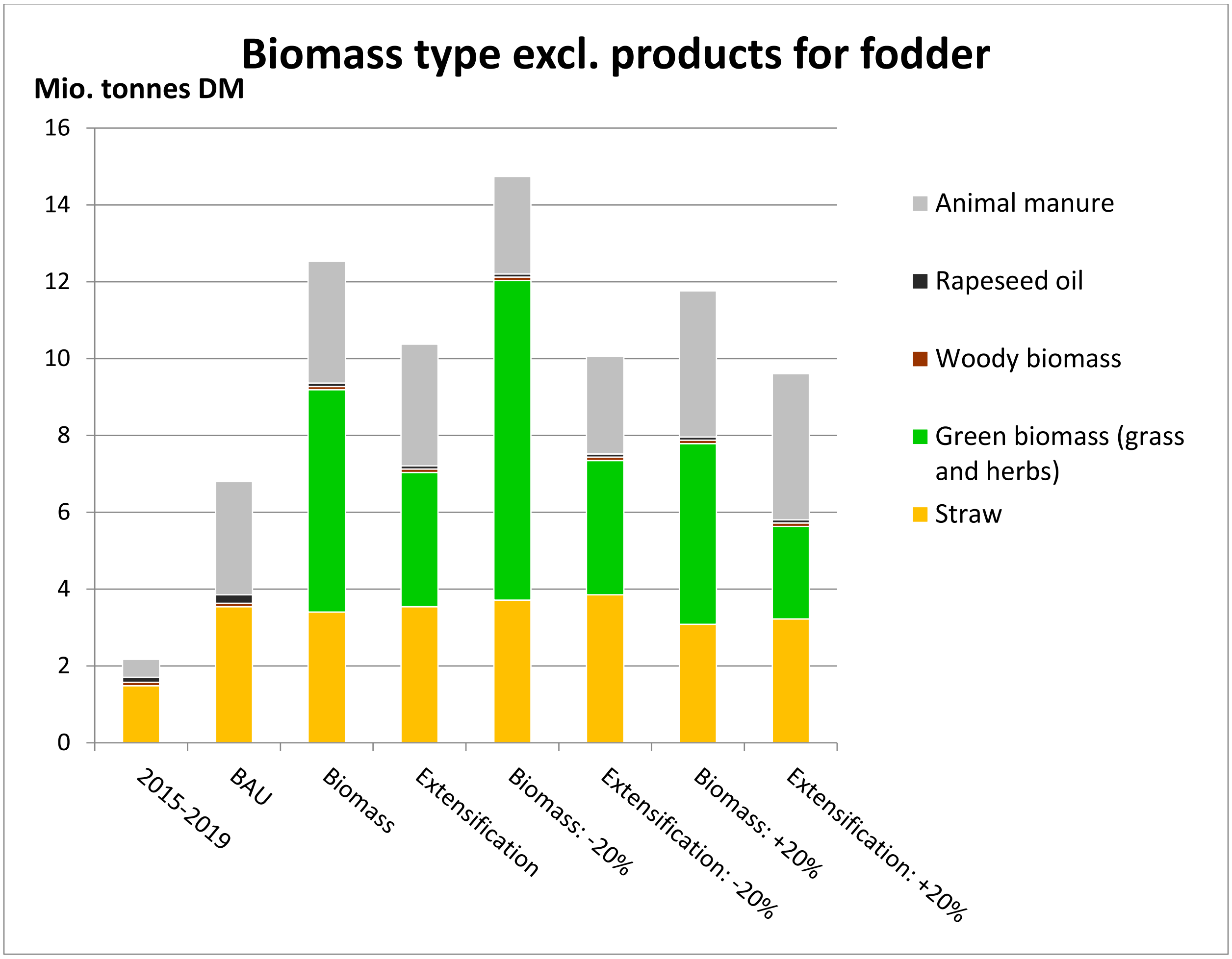

Figure 2: Biomass production on the agricultural area (million tonnes DM) for 2030-scenarios based on biomass type and usability. BAU = Business-As-Usual. "-/+20%" = scenarios with a 20% reduction/increase in Danish animal production. The required quantity of fiber from biorefining to substitute roughage crops from areas converted into biomass production is subtracted from these values.

Animal manure available e.g. for biogas production, is relatively similar throughout the 2030-scenarios, where the main differences are due to decreased or increased animal production. In the BAU-scenario, the quantity of animal manure available for e.g. biogas is comparable to the quantity in the optimized scenarios, due to biogas being a well-known technology. The share of animal manure utilized for biogas production has increased heavily from 2017 to 2020, and further increase is expected with existing policies. In relation to animal manure, the difference between BAU and the optimized scenarios is a more effective manure handling that is not included in BAU scenario.

Rapeseed oil plays a role for biorefining and energy purposes in the BAU scenario, but it is considered a high value raw material not adequate for direct energy use in the optimized scenarios. The majority of woody biomass is currently derived from forests, with short rotation coppice on agricultural soil as a minor component. Biomass from the forest is not included in figure 1 and 2. Depending on demand and economic incentives, woody biomass could be increased e.g. by substituting a share of the perennial grasslands for biorefining with short rotation coppice. However, this will reduce DM yield as the expected DM yield per year is lower for short rotation coppice (approx. 12 tonnes DM/ha) compared to intensive production of grass/clover (approx. 15 tonnes DM/ha). The afforestation on agricultural soils is not expected to provide biomass on this short timespan to 2030, while it increases C storage and potential for later use.

The area with sugar beets for biorefining in 2030 (approx. 44,000 ha in the biomass scenario while no sugar beet production in the extensification scenario) could be increased with a higher DM production on the expense of some of the large areas with grass/clover for biorefining. This would, however, reduce soil organic carbon, and slightly increase nitrate leaching. However, on the nitrate sensitive areas of this analysis, the area with sugar beets have already been maximized to a limit where they can still be in a 5-year cropping rotation with other annual crops. Therefore, a further increase in the area with sugar beets would have to be placed outside the nitrate sensitive areas. Lucerne or pure clover for biorefining is another alternative to grass-clover mixtures. Lucerne and clovers do not need an input of fertilizer N while producing a protein rich input for biorefining, and may thus have lower N_2O emissions from the soil.

6 Nitrate-sensitive areas

In all optimized scenarios for 2030, large areas of nitrate sensitive soils are converted from annuals (grain, maize and rapeseed) to crops for biorefining with lower levels of nitrate leaching (Figure 3). This area is calculated to meet 60% of the reduction target in nitrate leaching that have been postponed from the 2nd Water Plan Period (2015-2021) until after 2021 (Styrelsen for Vand- og Naturforvaltning, 2016). The areas are clustered in certain parts of Denmark (Mortensen and Jørgensen, 2022) due to certain catchments having substantially higher nitrate reduction targets compared to others. In ID15 catchments with a relatively low share of maize compared to other annuals, a larger area is also needed to meet the reduction targets, as the effect on nitrate leaching by converting grain or rapeseed to grassland is lower than conversion of maize. There is a potential overlap between some areas of nitrate-sensitive soils and the share of organic soils where land use is changed in the 2030 scenarios. Therefore, these areas need to be analyzed in detail to describe specific changes and overlaps for the different scenarios in case of implementation.

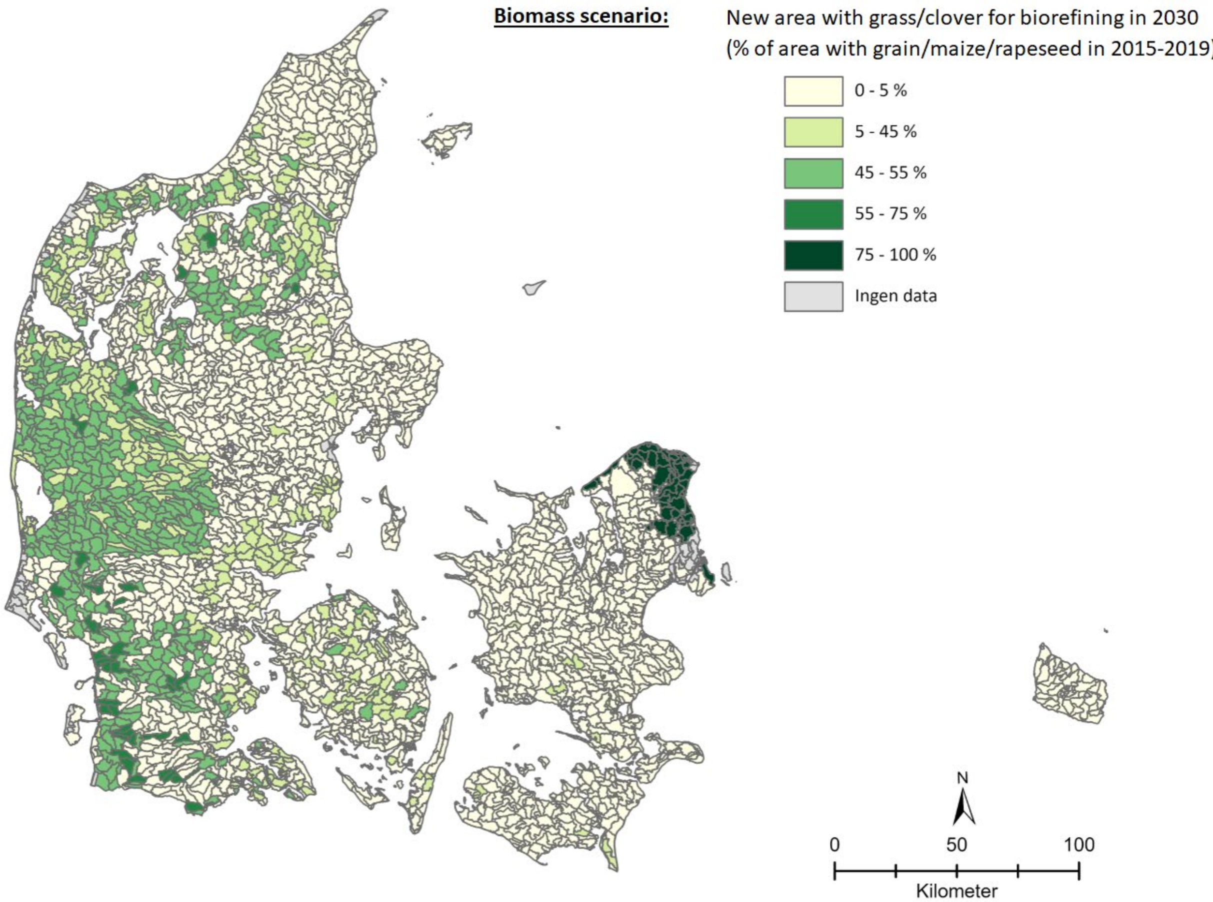

Figure 3: In the biomass scenario, an area of approx. 319,000 ha is converted from grain, maize and rapeseed into grass/clover (approx. 275,000 ha) and sugar beets (approx. 44,000 ha) for biorefining. In the extensification scenario, approx. 247,000 ha of grain, maize and rapeseed is converted into grass/clover for biorefining (with reduced fertilization). The specific area in each scenario (and its spatial distribution) is calculated by the empirical model NLES5 (Børgesen et al., 2020), in order to meet 60% of the reduction targets for each of the 23 main catchment areas that have been postponed from the 2. Water Plan Period (2015-2021) until after 2021 (Styrelsen for Vand- og Naturforvaltning, 2016). The remaining 40% is assumed to be reached by collective measures and other targeted measures. For all GIS maps look into background material (Mortensen and Jørgensen, 2022).

7 Land use changes on the agricultural area in 2030

The changes in agricultural production due to new areas of crops for biorefining affect the total national area available for food production. In 2017, approx. 0.05 million ha were used for bioenergy production, while this number increases to approx. 0.1 million ha in 2030 in the BAU-scenario due to afforestation and an increase in share of rapeseed oil used for energy. In the optimized scenarios for 2030, the area producing biomass for biorefining ranges from approx. 0.5 to 0.7 million ha (Figure 4), but this provides significant amounts of fiber used as feed to substitute converted areas with roughage crops, and high-value protein concentrate substituting soy import. If these fodder components are subtracted as a share of the total area with crops for biorefining, the total farmed area for biorefining for non-feed purposes is approx. 0.4 to 0.6 million ha in 2030 (Mortensen and Jørgensen, 2022). In the biomass and extensification scenarios, feed supply is maintained partly through the share of products from biorefining, and partly through an increase in import of grain and rapeseed (Figure 7). However, future biorefineries may provide food and feed components from many of the raw materials handled (even wood can be digested by microbes into valuable protein feed), and there is not a clear distinction between the uses for food vs non-food. In reality, market demands will determine what will be the most valuable to produce in the biorefinery.

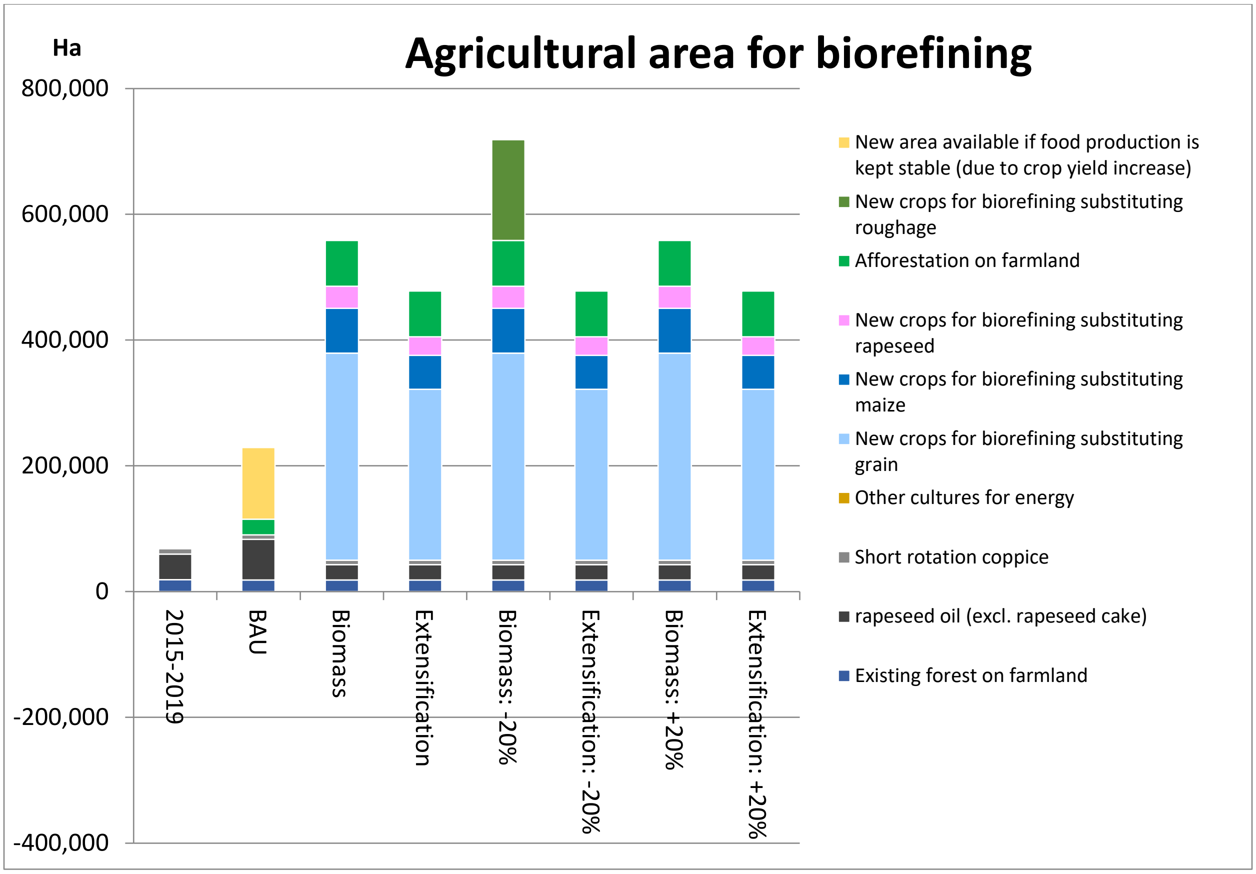

Figure 4: Differences in the total farmed area used for biorefining in 2030-scenarios. Yellow bar represents an excess area for farming in the BAU-scenario if food production is kept stable, due to expected yield increases (Dalgaard and Mortensen, 2022). Grain production for export is assumed on this area with average grain yield, without taking into account that certain parts of this area may not be suitable for grain production, or that other land uses such as forest or natural succession might be preferred. In the other scenarios, this excess area in used for crops for biorefining, with the result that grain import is higher compared to in BAU (Figure 7).

The large area of farmland converted into crops for biorefining affects the composition of different land uses on the agricultural area in Denmark (Figure 5), but also the area needed abroad to supply the Danish animal production (Figure 5). As roughage feed is not practically feasible for import, it is prioritized to produce all roughage feed needed in the specific scenarios, while reducing the area used for cereals and rapeseed. This results in a substantially lower grain export and in some scenarios a shift to a net import of grain.

In the scenarios with a reduced animal production in 2030, a net export of grain is possible, and soy import can be substituted by grass-protein from biorefining. The latter depending on whether land use change is targeted biomass production for biorefining or if extensification of the farmed area is preferred. In the scenarios with increased animal production, a substantial net import of grain is needed (in contrast to the significant grain export in the BAU-scenario), and soy import is substantial in both the biomass and the extensification scenario. Other land uses may compete with the components mentioned in this analysis, such as an expected increase in photovoltaics on agricultural soils.

In the scenarios with reduced animal production in 2030, the area used for net export of grain could potentially be converted into more areas for biomass production or nature instead. In the extensification scenario with a 20% reduction in animal production, an area for extensive grazing and natural succession of approx. 0.27 million ha is established on areas now used for farming (Figure 5). This area constitutes just above 10% of the farmed area in Denmark, and thereby this scenario will be the only one out of the seven 2030-scenarios to fulfil the EU target of 10% of the European farmland to be taken out of production (Altinget, 2020). In the biomass scenario with a 20% reduction in animal production, this number is only 0.6% but could be increased substantially if net export of grain was set to zero.

In the BAU scenario (and the biomass scenario), we assume the increase in organic farming to be divided equally on all crops, whereas in the extensification scenarios, we assume the further increase in organic farming compared to BAU, to be established on the new areas with grass/clover for biorefining. However, in reality a share of the area that is under organic farming today is likely to be turned into grass/clover in the 2030 scenarios in order to optimize the organic crop rotations of today. Also, a part of the increase in the extensification scenarios is likely to be allocated for other annual crops, with smaller changes in the proportions of yellow and green biomass compared with these results. Furthermore, is it important to consider whether the production of organic versus conventional grass/clover for biorefining will match the actual market demands.

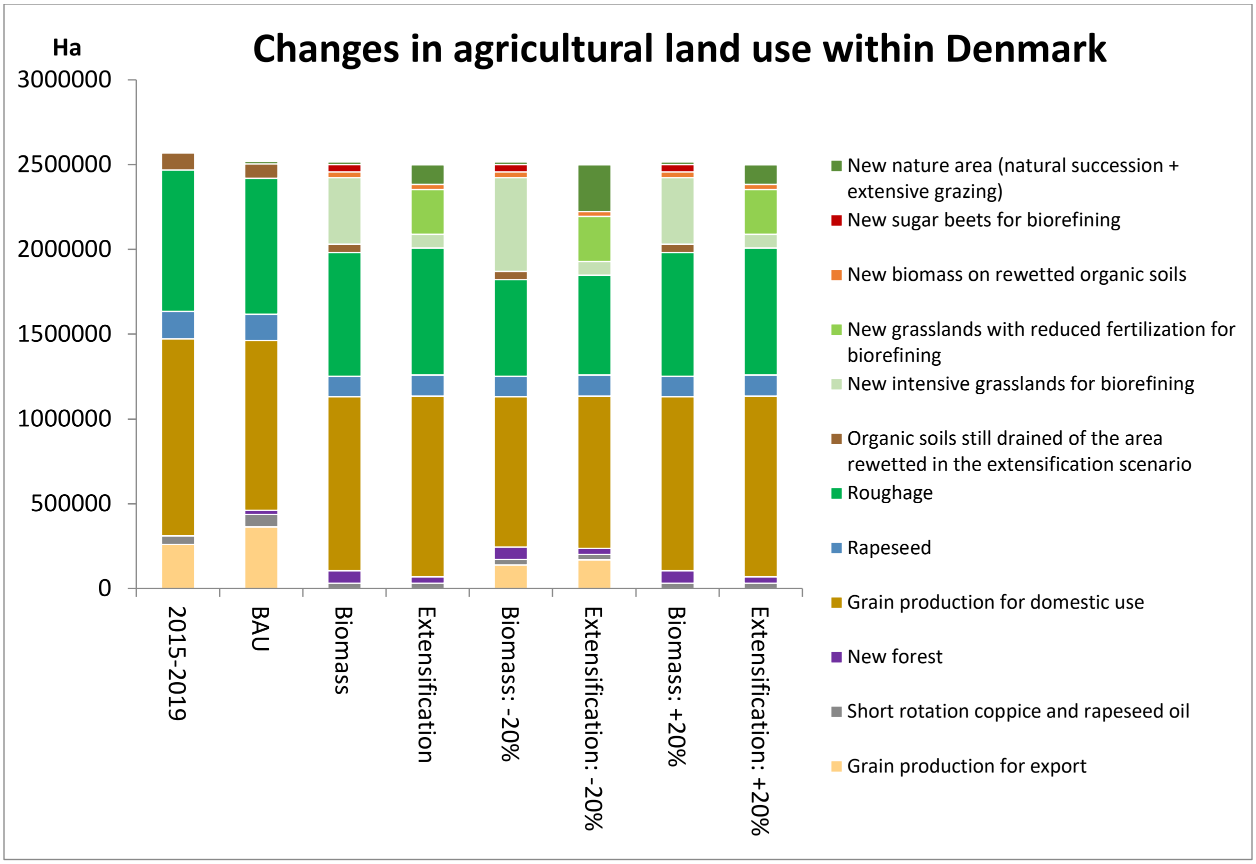

Figure 5: Estimated changed in land use on the agricultural area in Denmark for the different 2030-scenarios. The numbers only include the main agricultural crops, as production of minor productions and vegetables are kept stable in the scenarios. The total agricultural area is expected to be approx. 2.5 million ha in 2030 compared to 2.6 million ha in 2017.

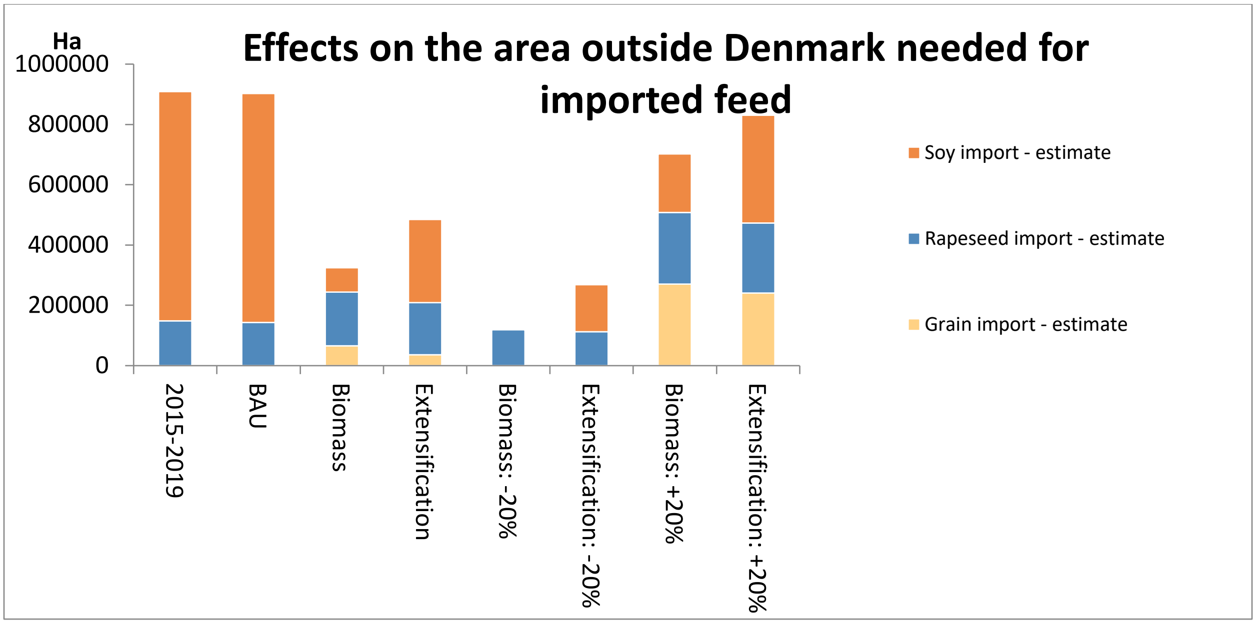

Figure 6: The area needed in others countries to produce the feed imported to Denmark (soy, rapeseed and grain) varies significantly between the scenarios for 2030. The area used for imported rapeseed and grain is calculated as an estimate by Danish mean yield across grain species and varieties (Statistikbanken, 2020), while the area used to grow imported soy is based on estimates by Callesen et al. (2020).

8 Import and export of cash crops in 2030

Import and export of grain, rapeseed and soy are significantly affected by the new area with crops for biorefining (Figure 7). A shift from grain export to grain import will occur unless the Danish animal production is decreased. However, while grain import increases, the new production of grass protein substitutes a large proportion of the soy import. Thus, overall a shift from soy import (expensive in both economic and environmental terms) to import of relatively cheap feed grain is the main consequence on the import/export balance. The potential export of grass protein, if all soy import can be substituted, seems only realistic in a scenario with a reduced animal production and optimization of the agricultural area for biomass production. Whether an excess of high-value grass protein should be exported for fodder or if it can be further refined into products for human consumption should be evaluated, as well as whether an area for producing protein-rich plants (e.g. peas and beans) for direct human consumption could substitute a share of the area with crops for biorefining. However, annual legumes for human consumption will have a higher N leaching compared to grasslands.

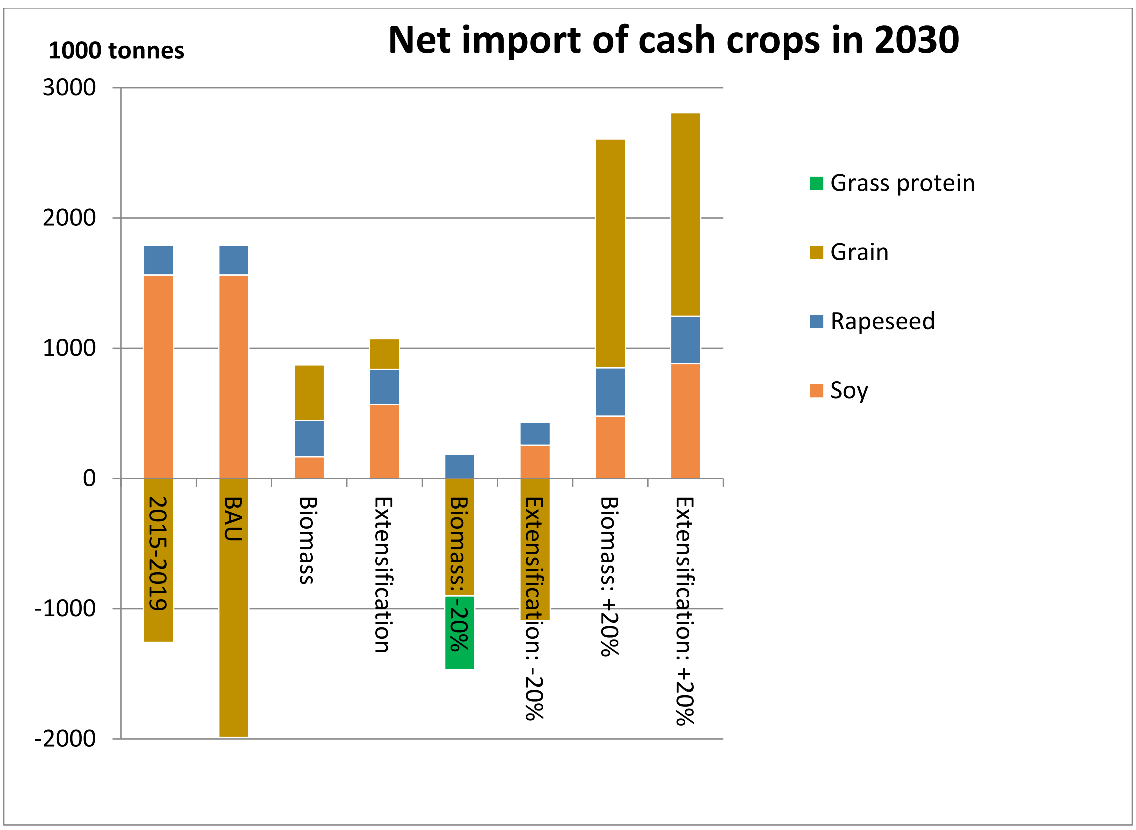

Figure 7: Estimation of the import/export balance of the most important cash crops for different 2030-scenarios. The increase in grain export in the BAU scenario for 2030 compared to baseline is based on using the entire excess area that theoretically comes due to crop yield increase and stable animal and food production in 2030. Positive values represents import, while negative values represents export.

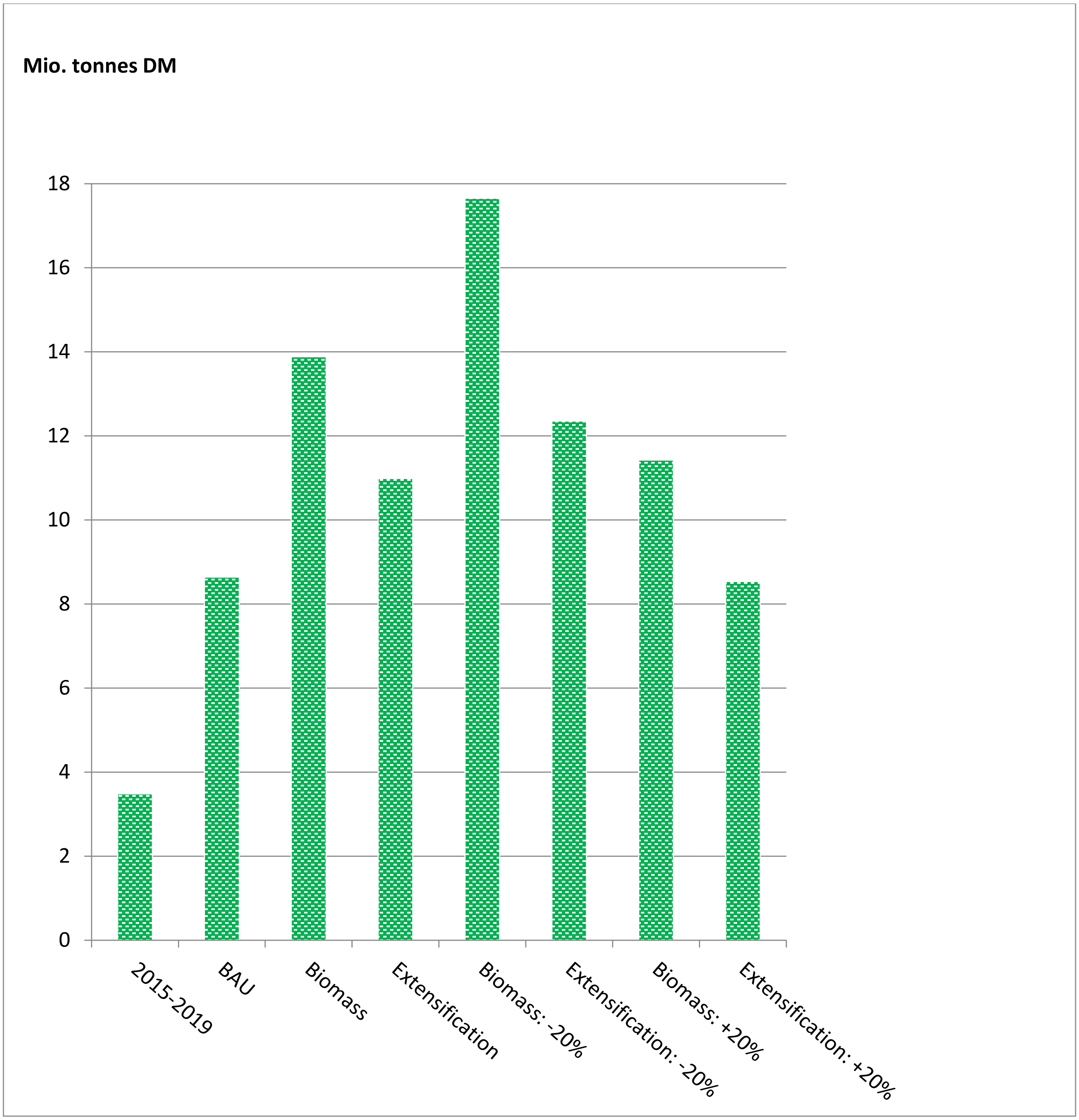

Figure 8: The net import (or net export) of cash crops (Figure 7) in million tonnes of DM is subtracted from (or added to) the total sum of biomass production available for biorefining (excl. products for fodder) (Figure 1).

Considering the large differences on the import/export balance of cash crops between the scenarios (Figure 7), DM values for the net import/export balance for these crops have been aggregated with the biomasses available for biorefining (Figure 1), to give an overview. This indicate that increasing the animal production does not only reduce the potential for production of biomass for biorefining in Denmark as shown in Figure 1, but taking into account the higher need of biomass production for fodder outside Denmark, this effect is even stronger. In addition, a 20%

increase or decrease in animal "biomass" in meat, egg and dairy products could be included in this graph to give the full overview of changes between scenarios.

9 References

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