Policy Instruments for the Efficient Use of Carbon Cascades in Agricultural Products

AARHUS
UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

Data sheet

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1   Introduction

The green transition requires that bioresources are generated and used such that they offer the greatest possible societal value for Denmark and globally. This value includes the economic gains in primary production and in the manufacturing industry, as well as the environmental benefits (Lerche et al. 2025). In line with this, the European Commission's new Bioeconomy Strategy suggests developing lead markets for materials and technologies through analysis and exchange of best practices on cascading use with a community of practitioners within the EC Knowledge Centre for Bioeconomy (EU COM 2025). With the Agreement on the Implementation of a Green Denmark of 18 November 2024 (Folketinget 2024), it was decided to establish an expert committee to address the challenges regarding agricultural crops and the cascading utilization of biogenic carbon therein. The expert committee was asked to deliver a vision targeting high socioeconomic gains, helping to reduce the import of feed protein, increase the production of sustainable goods and ensure more climate-friendly land use, while not putting commercial actors at disadvantage. In its report, the expert committee recommends that this can be achieved by increased vertical cooperation across value chains, which is argued to enhance social welfare and encourage innovation (Lerche et al. 2025). Co-location of vertically dependent activities is suggested to facilitate coordination, reduce transport needs and help to improve technological infrastructure. Vertical integration into larger firms is also argued to facilitate risk taking with respect to innovation and patenting. It is further recommended to prioritize the production of more highly valued products.

The purpose of this memorandum is to review the literature on policy instruments and their relevance for promoting the socioeconomically efficient use of carbon cascades in agriculture. Particular attention is given to the design of economic incentives for increasing grass production and its subsequent utilization in biorefineries. The memorandum seeks to provide an answer to the following two research questions: (1) What policy instruments can enhance the socioeconomically efficient use of carbon cascades? and (2) How can these instruments be applied to incentivize grass-based biorefinery value chains?

The memorandum is organized as follows: Section 2 reviews alternative definitions of the concept carbon cascades. Section 3 compares alternative models of material flows and the economy and their relevance for choosing policy instruments. Section 4 reviews empirical economic studies of grass-based biorefineries in Denmark and policy instruments applied within the value chain. Section 5 provides a discussion and conclusions.

2   Alternative definitions of carbon cascades

There is no consistent and generally agreed definition of the term carbon cascades (or the related term biomass cascades) across science, economics and politics (Fehrenbach et al. 2017; Olsson et al. 2018). Common to the definitions that are provided is the focus on the sequential use of a resource for different purposes (Olsson et al. 2018). However, there are fundamentally different guidelines for how decisions on resource use should be made. For example, the term carbon cascades is used in an EU Commission staff working document for the EU Bioeconomy strategy (EU DG-RI 2012) to define the joint decision on a main product and its by-products, or on several simultaneously produced co-products, when the purpose is to maximize value added of the biomass used. One can note that the economic term 'value added' expresses the difference between the market value of a product and the costs for the inputs used for its production, i.e. the welfare effect of a given stage of production.

A second definition appears in the recent debate on woody biomass, where cascading is often presented as a hierarchy, where material use of wood should hold priority over energy use of the same biomass (Olsson et al. 2018). This approach is at least partly based on the idea that certain forms of biomass utilization are inherently more valuable than others, while the precise motives for the value hierarchy are often not stated (Olsson et al. 2018). One problem with this definition is that such a value hierarchy might not remain stable over time. For example, choices on biomass use have significant effects on carbon uptake and release from terrestrial systems. The socioeconomic value of this uptake and release will increase over time with the urgency of climate change. This is reflected in an increasing carbon price over time (Pindyck, 2019; Gollier, 2021). Hence, biomass use that increases the uptake of carbon from the atmosphere (or reduces the release) will become successively more valuable over time compared to other ways of using the biomass. Also, the substitutability between biomass-based products and other products will change over time due to technological development, implying that the socioeconomic value of the biomass-based product will also change (Olsson et al. 2018).

A third strand of studies suggests that cascading use of biomass should be defined as a biomass final product being used first as a material, then if possible re-used as another type of material, while eventually being used for energy purposes (Fehrenbach et al., 2017). This definition thus focusses on recycling of biomass material.

2.1   The expert committee's definition of carbon cascades

The expert committee defines carbon cascade utilization such that one should prioritize the use of bioresources for higher-value products first, then utilize residual products for successively lower-value products. In line with that it is indicated that grass proteins could first be extracted for food or feed (e.g. via fermentation), while the remaining fibers could be used for materials. At the end, a residual product can be utilized in, e.g. biogas plants, where the nutrients are recycled as a fertilizer product and the carbon in residual fibers is stored as biochar (Lerche at al. 2025). This definition aligns with that provided by the Danish Bioeconomy Panel (2024).

Comparing the expert committee's definition, provided in Lerche et al. (2025), to the three above-mentioned definitions in the literature, the committee postulates a value hierarchy but does not explicitly motivate this. It can further be observed that Lerche et al. (2025) acknowledges that for the products defined by them as being of high value, innovation is needed to either reduce production costs or improve the quality of the final product. This suggests that the product is currently not profitable enough for private companies to engage in the production. Moreover, Lerche et al. (2025) do not discuss how environmental externalities affect the socioeconomic value of different biomass-based products. Hence, the postulated value hierarchy seems neither to reflect the value added to the agents in the value chain nor to reflect the socioeconomic value of different biomass-based products.

2.2 Conclusion on the choice of definition of carbon cascades

Given the aim of this report to study the socioeconomically efficient use of carbon cascades, the definition of carbon cascades provided in Lerche et al. (2025) is not suitable. This is because it does not explicitly recognize the economic aspects of the value of different biomass-based products. In contrast, this economic aspect is considered in the definition provided by the European Commission (EU DG-RI, 2012). In the following, this definition is therefore taken as a point of departure. In addition, the report will distinguish between the private value added, which is here defined as the welfare effect to producers and consumers from the production of a biomass-based product and the social value added, which is here defined as the sum of the welfare effect on producers, consumers and the welfare value of the environmental externalities generated.

3 Material flows and the economy

The growing role of biomass use requires an understanding of the way that materials and substances flow through the economy. Many different types of models are available for this purpose, and they each have their merits and shortcomings. In the following, a couple of different models: Substance Flow Models (SFA), Life Cycle Assessment Models (LCA), Partial Equilibrium Analysis (PEA) and Biomass Cascade Models (BCM), are briefly described with respect to their treatment of material flows and suitability for drawing conclusions relevant to policy or policy instrument choice.

3.1 Substance Flow Models (SFA)

Substance Flow Models (SFA) are based on so called environmental input–output analysis. The flow of materials or substances between different commodities produced is described by a matrix (Bouman et al., 2000). The data in this matrix can be seen as technical coefficients. These coefficients are assumed to be constant, i.e. independent of the scale of production, which is a simplification when compared to reality. SFA models do not consider the economic decisions made by producers and consumers, i.e. how these agents respond to prices changes. The main strength of these models is in their ability to describe the technical relationships within a complex value chain.

To assess policy decisions in the context of an SFA model, the analyst needs to choose one or more fairly extreme packages of measures to explore the impact on the material flows, including both the overall resource use, the flow among commodities and the residuals emitted to the environment (Bouman et al., 2000). For example, one could examine the consequences of prohibiting the production of a commodity; doubling the demand for a commodity; or applying a new technology that reduces the residuals from the production of a commodity by half. Economic impacts, such as the consequences for commodity prices, producer profits and consumer welfare, cannot be assessed by these models (Bouman et al., 2000).

3.2 Life Cycle Assessment Models (LCA)

Life Cycle Assessment (LCA) models are used to assess the environmental consequences of a product from cradle to grave, considering resource extraction, manufacturing of materials and energy, manufacturing of the product, use, maintenance and waste treatment. Typically, only the variable inputs are considered in the model while the role of fixed capital, such as land and machinery, is not made explicit in the model (Bouman et al., 2000). LCA usually focuses on the function of a final product rather than the product itself. Different technological alternatives for producing this function can then be considered and the associated environmental impacts over the whole life cycle can be assessed. LCA considers only the impacts per unit of the function of a commodity, implying that it does not consider the market volume of different products. Hence, changes in market volumes due to technical innovation or policy instruments cannot be assessed (Bouman et al., 2000).

3.3 Partial equilibrium analysis (PEA)

Partial equilibrium models (PEA) inform on the outcome on a market, or a set of markets, by describing the economic decisions that determine the outcome. They consider how consumers and producers respond to price changes in this market. Producers' decisions are also determined by the production technologies available to them. The impact of a change in, for example, an agri-environmental support schemes on the consumption and production of different commodities that are directly or indirectly related to the supported commodity can be determined. Whereas these models provide further insights into consumer and producer responses and the welfare implications for those, the additional complexity requires that the models are simplified with respect to the direct inclusion of material and substance flows, compared to SFA and LCA. However, market shares of different products can be assessed, which is an advantage compared to LCA models. Thus, the impact of agri-environmental policies on resource use, residuals, market shares and consumer and producer welfare can be assessed, but the technological relationships are simplified compared to the previously mentioned models (Bouman et al., 2000).

The simplified technological relationships used in PEA models can be obtained from LCA models. It is then possible to examine the welfare-economic consequences of setting a target or constraint on emissions. An alternative to that approach is to use a PEA model not including emissions to first simulate the impact of a change in agri-environmental policy on output produced, resources utilized for production and the economic consequences thereof. The information on resource use and output produced can then be transferred to an LCA model, where it can be used to get further information on the environmental impact from different stages of production, due to the agri-environmental policy in question. Examples of this latter approach are provided by Cong and Termansen (2016) and Salou et al. (2019), mentioned below.

3.4 Biomass Cascade Models (BCM)

Given the diverse definitions of BCM, it is not possible to provide a general description of the method. Generally, the cascading approach implies a chain of sequential uses, where the biomass resource is first used for the purpose with the highest possible "quality" and the remaining resource is used for the highest quality purpose then available given the state of the remaining biomass resource and so on (Olsson et al., 2018). The quality indicator could be "inherent", be the market price of the product or be the value added. The two latter will by necessity change over time as prices change and new technologies are developed. Of those, only the value added will indicate the socioeconomic benefits of the uses. The relative advantages of BCM and LCA models when applied to real world examples are not well understood, because of the diversity of empirical examples studied with each of the methods (Thonemann and Schumann, 2018).

The focus of the discussion of policy in relation to biomass cascades has mainly concentrated on whether biomass should be used for materials or energy (Olsson et al., 2018). Attempts to introduce regulations to control the purpose of biomass use in line with this includes the Swedish Wood Fiber Law in place between 1978 and 1993 and the Flemish Materials Hierarchy Regulation in place between 2008 and 2013. The Swedish Law is shown to hold back forest industry development, lead to increased imports and increase the role of lobbying efforts, which benefitted large market actors and organizations at

the expense of smaller agents (Brännlund et al. 2010; Lundmark and Söder-holm, 2004). Moreover, the regulation quickly became redundant because the industrial demand for wood fell over time (Olsson et al. 2018). The Flemish regulation gave the wood and paper industry authority to decide if a given wood resource should be used by the industry or be eligible for energy use. This created problems for the electricity sector that could not acquire enough green certificates. The regulation was first loosened up, then abandoned (Olsson et al. 2018). Common to these attempts to regulate biomass hierarchies is that they create lock-in effects where changes in market demand for different commodities and introduction of new innovations can be hindered.

3.5 Advantages and disadvantages of models for identifying economically optimal utilization of bioresources

The choice of material flow models has implications for the understanding of the socioeconomic and environmental impacts of a value chain. SFA and LCA models are useful for understanding the impacts of a value chain on the environment, in particular the emissions generated. SFA models are additionally useful to understand natural resource stocks, such as for example biomass, nutrient and carbon stocks. Neither of these model types account for economic behavior in terms of the response of consumers and producers to price changes.

BCM approaches focus on the prioritization between different competing uses of the same biomass. If the prioritization is made based on commodities "inherent" values or commodity prices, a BCM approach will not lead to the best possible socioeconomic outcome in terms of welfare gains to consumers and producers, and environmental externalities. If prioritization builds on socioeconomic value added, including impacts on consumers, producers and the environment, the BCM approach could help to compare socioeconomic outcomes for different uses of bioresources.

PEA models can account for both material flows and economic behavior by consumers and producers. Due to the additional complexity implied by the incorporation of economic behavior, the description of material flows is simplified compared to SFA and LCA models and focuses on the most important flows.

3.6 Using models to analyze policy and policy instruments

SFA models can be used to assess rough policy scenarios in terms of, e.g. a given increase in the demand for a commodity, a given reduction in the availability of a resource or a given improvement of the technology used in a particular part of the value chain. The outcome of such an assessment is the impact on the supply of different commodities throughout the value chain. However, socioeconomic impacts cannot be derived.

LCA models can be used to compare alternative value chains, facilitating choices between different means to deliver a given function or commodity. This could be useful if one wants to identify a policy that regulates the use of certain technologies. However, economists generally do not advise policy makers to regulate the use of specific technologies, but rather to provide technology-neutral incentives, instead focusing on encouraging emission reductions independently of the technology used to achieve them (Hasler at al. 2022).

PEA models are useful for decisions on policy instruments if the policy maker wishes to simultaneously assess the economic impacts on producers and consumers and impacts on resource use, supply and emissions across a value chain. Moreover, they can be used to identify the optimal level of an economic incentive such as an environmental subsidy or tax. The level of such economic incentives can be adjusted when the economic, technological and environmental context changes over time. Essential for the quality of the model is that material flows are described in a relevant manner, implying that SFA, LCA and PEA models can be complementary.

BCM approaches have not proven a useful basis for policy decisions when building on the assumption of an "inherent" quality ranking among biomass-based commodities or on products' relative prices. If the quality ranking builds on value added, including environmental externalities, a regulation of biomass use could be economically optimal. However, as prices and technologies change over time the value added will also change and the regulation could create costly lock-in effects.

4 Economic studies of the grass-biorefinery value chain

This section first provides a brief description of the grass-based biorefinery value chain. Thereafter, it seeks to provide an answer to the following two questions: (1) Will grass-based biorefineries add financial value to the value chain agents and economic value to society as a whole? and (2) What is the impact of economic instruments applied to the grass-biorefinery value chain? In both cases, the answers are based on the existing scientific literature.

4.1 Brief description of grass-based biorefinery value chain

Grass-based biorefineries can generate green alternatives to conventional products including feed, food, building materials, packaging and natural gas. The grass-biorefinery value chain could also benefit the environment: Conversion of agricultural land to grassland can bring climate benefits: Grass proteins for animal and human consumption can replace food and feed sources with a larger carbon footprint such as meat, dairy products and soy; grassland crops can contribute to increased soil carbon sequestration; and grass biomass can be used as an input to biogas plants, which can reduce climate impact when biogas displaces fossil fuels (Lerche at al. 2025).

4.2 Cost-benefit analyses of grass-based biorefineries in the Danish context

This section reviews three studies applied to the grass-biorefinery value chain in the Danish context. Common to the three studies is that they apply a cost-benefit approach, studying the costs and revenues for the private agents in the value chain for a single, smaller, hypothetical biorefinery project. Only one of the studies, Martinsen and Andersen (2020), also examines the costs and benefits associated with a larger biorefinery plant and assesses the economic value of the impact on externalities.

Martinsen and Andersen (2020) study the financial and welfare economic effects of producing green proteins for feed at a biorefinery, where the biorefinery is co-located with a biogas facility, hence saving on transportation costs. The study uses a cost-benefit analysis. Two different scenarios are considered that differ with respect to the biorefinery's overall production volume, biogas investment needs and the use of residuals from protein production. In the case with a small production volume (20,000 tonnes of dry matter), only the residual juice fraction is assumed to be used by the biogas plant, while fiber residuals are used as cattle feed. In the case with a large production volume (150,000 tonnes of dry matter), all residuals are used for biogas generation, implying larger needs for investments in the biogas plant. The protein production in the biorefinery is assumed to use highly fertilized grasses (450 kgN/ha) that replace conventional crops on the land where they are cultivated. The welfare economic analysis considers greenhouse gas emissions, air pollution (sulphur oxides, nitrogen oxides and particulate matter), nitrogen and phosphorus leaching, cadmium and transportation.

The financial analysis in Martinsen and Andersen (2020) shows that the small-scale plant can generate a modest surplus to the biorefinery owners, while the

large-scale plant will be making modest losses. For this to be achieved, considerable public spending, in terms of biogas feed-in tariffs, is needed. Both scenarios yield a negative welfare economic result. This is because the overall impact of the externalities is negative.

The study by Martinsen and Andersen (2020) has some limitations. First, it does not assess price effects that would follow from scaling up biorefinery production of green proteins across the country. If the production is scaled up, this would likely imply that the production cost and farm-gate price of grass increases when grass cultivation successively replaces more valuable agricultural crops. Second, feed-in tariffs could be interpreted as the benefits that society assigns to biogas, due to the ability of biogas to displace fossil fuels. Over time, these benefits can be expected to fall as society transitions towards a larger share of renewables in the energy mix. Increased biogas production can therefore be expected to increasingly displace other renewable energy sources in the future. The climate benefits from increased biogas production then falls. Another limitation, mentioned by Martinsen and Andersen (2020), is that the climate related value of biorefinery-based green proteins, due to their displacement of imported soy, is not accounted for in the study. Summing up, the two first limitations would, if addressed, reduce the welfare economic benefits of the grass-biorefinery value chain, while the last might increase the net benefits.

A similar but more compact assessment of the grass-biorefinery value chain is made by Jørgensen et al. (2021). They study only a smaller biorefinery (20,000 tonnes of dry matter). Three scenarios are compared, differing in the assumptions about the prices for the grass input and the price of the grass-based protein. In one scenario, both prices are set equal to those for conventional products, in another the output price is set equal to that for GMO-free products while the input price is that for conventionally grown grass, and in the third scenario both prices are set equal to those for organic grass and organically produced protein, respectively. Results suggest that protein produced from conventional grass and competing with conventionally produced alternatives has the lowest net revenues, profits being negative. If the protein product is instead competing with GMO-free alternatives the net revenues are higher and positive. The scenario with organically based production produces the highest revenues.

The limitations mentioned for the study by Martinsen and Andersen apply here as well. In addition, Jørgensen et al. (2021) do not consider environmental externalities and, hence, do not calculate welfare economic effects.

Cong and Termansen (2016) combine cost-benefit analysis with life-cycle analysis to analyze the grass protein from a green biorefinery as a substitute for cereals in pig feed. The results show that with a small-scale green biorefinery, pig feed costs would decrease somewhat compared to a system with traditional cereal-based feeding, and the biorefinery would obtain a small positive profit. The study only considers two externalities: nitrogen leaching to the aquatic environment, which would fall when the grass-biorefinery project is implemented and nitrogen oxide emissions into the air (contributing to climate change), which would tend to increase when the project is implemented. The authors argue that large-scale application of green biorefineries under current Danish conditions may not be profitable because of the considerable investment cost for these biorefineries. Moreover, if large biorefineries are built, the logistic costs could become considerable given the transport

needs for the bulky input as well as for the output. This fact could favor small biorefinery plants.

The limitations mentioned for the two above studies apply for Cong and Termansen (2016) as well. Although Cong and Termansen (2016) estimate nitrogen leaching and nitrous oxide emissions from the project, the economic value of the emissions is not accounted for and, hence, no welfare economic calculations are made. It should also be noted that fewer externalities are considered than in Martinsen and Andersen (2020).

Taken together, the three studies provide weak evidence that small scale biorefineries could be privately profitable in the Danish context, while the studies do not provide support for the profitability of large scale biorefineries. Only Martinsen and Andersen (2020) carry out analysis of the socioeconomic effects of biorefineries, taking externalities into account. That analysis suggests that there is an overall negative economic impact on the environment, implying that public interventions to support green biorefineries would not be warranted.

4.3   Policy instruments relevant to the grass-biorefinery value chain

The expert committee on carbon cascades observes that the development of an economically viable grass-biorefinery value chain requires a lower grass price than currently found on the market (Lerche at al. 2025). This conclusion is supported by the studies mentioned in the previous section. More generally, for the grass-based protein to be competitive with imported soy protein, the biorefinery's production costs need to be lower (Lerche at al. 2025). This could be achieved also through innovation of new technologies, provided that the technological development is faster for grass-based refineries than for competing products.

A study by Salou et al. (2019) examines the impact of a grass premium on the French agricultural sector. This study is relevant through the focus on incentivizing grass production. The study does not include biorefineries, but some lessons of the potential impact of a grass premium can still be drawn. No other studies have been found examining support directly targeting biorefineries.

More specifically, Salou et al. (2019) investigate the impacts of a grass premium on the French ruminant sector. The study first simulates the impact of this grass premium on the agricultural outputs produced and the resources utilized for production and examines the economic consequences thereof. This first step is carried out using an agricultural sector model. Such models account for price responses by producers and consumers and inform us about the resulting prices and market shares of different outputs. Next, the information on input and output quantities is transferred to an LCA model, which is used to calculate the environmental impacts that follow from the introduction of a grass premium, including greenhouse gases; eutrophying, acidifying and toxic substances; ecosystem impacts and energy use.

The results in Salou et al. (2019) show that a grass premium will shift cattle diets towards containing less concentrates and more grass, and grassland expands at the expense of cropland. The volume of ruminant products is hardly affected due to the low price sensitivity. Crop production is intensified on the

remaining crop land. All considered environmental externalities were reduced.

Based on the study by Salou et al. (2019) one might draw some conclusions for the impact of a grass premium on the biorefinery value chain, although caution is needed when transferring the results to the Danish context. First, a grass premium might improve the financial situation of biorefineries, because with a larger supply of grass on the market the price can be expected to fall. In addition, farmers that cultivate grass will make financial gains as for a considerable number of farmers, the production costs will be lower than the grass price, including the premium. Also, livestock owners that purchase grass as silage would gain financially from the lower price. The distribution of the financial gains across the three agent types would be determined by their responsiveness to price changes. Second, a grass premium would likely lead to intensification of crop production on the remaining cropland. As the suitability of land for crop and grass production varies with local conditions such as soil types and local climate, this could lead to increased nitrogen emissions in locations where arable crop production is comparatively more favorable than grass production. However, the risk for increased nitrogen emissions will likely be further regulated under the new emission-based N-regulation implemented from 2027, where each farm is allocated an N-emission quota.

5   Discussion and conclusions

The purpose of this memorandum is to examine what policy instruments can enhance the socioeconomically efficient use of carbon cascades and how these instruments can be applied to incentivize grass-based biorefinery value chains. The work is related to the report provided by the expert committee on cascading utilization of agricultural carbon and the suggestions therein to strengthen the Danish grass-based biorefinery production of proteins for food and feed (Lerche et al. 2025). The analysis builds on a review of the literature.

The first step in this work was to compare the carbon of biomass cascading approach as a tool to make trade-offs between alternative uses of biomass. This showed that there exists no uniform approach to carbon or biomass cascading. However, common to the approaches is that they build on a value ranking of alternative uses. This ranking can build on assumptions about an "inherent" value, typically assumed to be higher for more refined products, or on product prices or the value added in a certain stage of the value chain. Seemingly, the report by Lerche et al. (2025) builds on the assumption about an "inherent" value, assumed to be higher for more refined products. If decisions are based thereon, it is unlikely that the outcome will be socioeconomically efficient. Instead, a socioeconomically efficient use of scarce bioresources requires that the resource is used such that it delivers the highest possible economic net benefits to society. These net benefits are determined by the prices consumers are willing to pay for different products, the costs of production and the value of the environmental externalities from the production as well as consumption of the products. To assess these net benefits, a combination of substance flow models, life cycle analysis models and partial equilibrium models are suitable tools. Partial equilibrium models also account for production costs and market responses. This is necessary to identify the socioeconomically optimal level of economic incentives (e.g. environmental taxes and subsidies) and to assess the resulting market shares of different products.

The next step in the work was to review empirical studies on the grass-biorefinery value chain in Denmark and studies on the impact of policy instruments applied to the value chain. This showed that small scale grass-based biorefineries could potentially be profitable for the value chain, while it is unlikely that large scale plants will be profitable under current conditions. Results from these studies also indicate that if environmental externalities are accounted for there will be negative economic outcomes for both small- and large-scale plants. Hence, there is at present no scientific support for environmental subsidies targeting biorefineries. An examination of studies assessing previous attempts to regulate bioresource use building on the assumption about an "inherent" value shows that these attempts have proven unproductive and the regulations were abolished. A study examining the effect of a subsidy to grass production showed significant impacts on grass production, price and utilization, but with minor impact on the size of the ruminant sector, illustrating the importance of price effects for the economic impact on the value chain. In addition, the subsidy had a beneficial environmental impact.

To better understand the potential of the grass-biorefinery value chain in the Danish context, future research could focus on assessing the price sensitivity of supply and demand for grass and on assessing the economic and environmental impact of potentially promising biorefinery innovations.

References

Bouman, M., Heijungs, R., Van der Voet, E., van den Bergh, J. C. & Huppes, G. (2000). Material flows and economic models: an analytical comparison of SFA, LCA and partial equilibrium models. *Ecological Economics*, *32*(2), 195-216.

Brännlund, R., Lundmark, R. & Söderholm, P. (2010). Kampen om skogen: koka, såga, bränna eller bevara?. SNS förlag; 228 p.

Danish Bioeconomy Panel (Det Nationale Bioøkonomipanel). (2024). Avanceret bioraffinering og kaskadeudnyttelse. As available 15 January at https://mgtp.dk/Media/638799683231552196/Avanceret%20bioraf-finering%20og%20kaskadeudnyttelse.pdf

EU COM (European Commission). (2025). Communication from the Commission to the European Parliament, the Council, the European Economic and Social committee and the Committee of the Regions: A Strategic Framework for a Competitive and Sustainable EU Bioeconomy, COM(2025) 960 final.

EU DG-RI (European Commission: Directorate-General for Research and Innovation). (2012). Innovating for sustainable growth – A bioeconomy for Europe, Publications Office of the European Union. As available 5 November 5, 2025 at https://data.europa.eu/doi/10.2777/6462

Fehrenbach, H., Köppen, S., Kauertz, B., Detzel, A., Wellenreuther, F., Breitmayer, E., Essel, R., Carus, M. Kay, S., Wern, B., Baur, F., Bienge, K. & von Geibler, J. (2017). Biomass cascades: increasing resource efficiency by cascading use of biomass—from theory to practice. German Environmental Agency, Heidelberg. As available 5 November 5, 2025, at https://www.um-weltbundesamt.de/sites/default/files/medien/1410/publikationen/2017-06-13_texte_53-2017_biokaskaden_summary.pdf

Folketinget. (2024). Aftale om implementering af et grønt Danmark. 18 November 2024. As available 8 December 2025 at https://regeringen.dk/ak-tuelt/publikationer-og-aftaletekster/aftale-om-implementering-af-et-groent-danmark/

Gollier, C. (2021). The cost-efficiency carbon pricing puzzle (CEPR Discussion Paper No. 15919). CEPR Press. As available 5 November 5, 2025, at https://cepr.org/publications/dp15919

Hasler, B., Termansen, M., Nielsen, H. Ø., Daugbjerg, C., Wunder, S. & Latacz-Lohmann, U. (2022). European agri-environmental policy: Evolution, effectiveness, and challenges. *Review of Environmental Economics and Policy*, *16*(1), 105-125.

Jørgensen, U., Kristensen, T., Jørgensen, J.R., Kongsted, A.G., De Notaris, C., Nielsen, C., Mortensen, E.Ø., Ambye-Jensen, M., Jensen, S.K., Stødkilde-Jørgensen, L., Dalsgaard, T.K., Møller, A.H., Sørensen, C.G., Asp, T., Olsen, F.L. & Gylling, M. 2021. Green biorefining of grassland biomass. 121 pp. Advisory report from DCA – Danish Centre for Food and Agriculture, Aarhus Universitet.

Lerche, A., Hansen, A. M., Christensen, B. B., Nielsen, B. S., Ravn, C. G., Hauberg, D., Capion, K., Thygesen, L.G., Ingerslev, M. Ambye-Jensen, M., Nielsen, O-K. Egemose. S. & Bitsch, S. (2025). Ekspertudvalget for kaskadeudnyttelse: Overordnet vision og anbefalinger for kaskadeudnyttelse i den grønne omstilling–med fokus på bioressourcer fra landbrugsafgrøder og skovbrug.

Lundmark, R. & Söderholm, P. (2004). Brännhett om svensk skog: En studie om råvarukonkurrensens ekonomi. SNS förlag. As available 25 November 2025 at https://snsse.cdn.triggerfish.cloud/uploads/2020/02/rapport-brannhett-om-svensk-skog.pdf

Martinsen, L., Andersen, M.S. 2020. Environmental and socio-economic analysis of integrated grass biorefinery scenarios. Aarhus University, DCE – Danish Centre for Environment and Energy, 91 pp. Scientific Report No. 383

Olsson, O., Roos, A., Guisson, R., Bruce, L., Lamers, P., Hektor, B. & Hildebrandt, J. (2018). Time to tear down the pyramids? A critique of cascading hierarchies as a policy tool. *Wiley Interdisciplinary Reviews: Energy and Environment*, *7*(2), e279.

Pindyck, R. S. (2019). The social cost of carbon revisited. *Journal of Environmental Economics and Management*, 94, 140-160.

Salou, T., Le Mouël, C., Levert, F., Forslund, A. & van Der Werf, H. M. (2019). Combining life cycle assessment and economic modelling to assess environmental impacts of agricultural policies: the case of the French ruminant sector. *The International Journal of Life Cycle Assessment*, *24*(3), 566-580.

Thonemann, N. & Schumann, M. (2018). Environmental impacts of wood-based products under consideration of cascade utilization: A systematic literature review. *Journal of Cleaner Production*, *172*, 4181-4188.