Optimised biomass usage in electricity and district heat production towards 2040

Published by:

Ea Energianalyse
Gammeltorv 8, 6 tv.
1457 København K
T: 88 70 70 83
E-mail: info@eaea.dk
Web: www.eaea.dk

1 Main results and perspectives

Introduction and purpose
This report is a summary of the report Optimeret biomasseanvendelse til el- og fjernvarmeproduktion mod 2040 prepared by Ea energy analyses in 2021 for the danish green think tank Concito.

CONCITO requested an analysis of the optimal biomass use in the Danish electricity and district heating sector towards 2030 and 2040. The analysis should take into consideration the most recent knowledge concerning how combustion of biomass results in a carbon release from the biogenic carbon pool.

Based on the report "CO_2 emission mitigation through fuel transition on Danish CHP and district heat plants" (IGN, 2020), an average CO_2 coefficient for biomass was calculated and applied to a number of Danish plants, the results of which are described in this report. The emission coefficient is 35 kg CO_2/GJ forest biomass, and it expresses the net CO_2 emissions of burning biomass over a 30-year perspective. The CO_2 coefficient depends on how biomass would alternatively be degraded over time and whether the growth of the forest changes. It can be assumed that increased demand for biomass globally will increase competition for forest products and that this could increase both the marginal and average CO_2 coefficients. Conversely, reduced demand for biomass is likely to lead to lower marginal and average CO_2 coefficients. It is unclear how the new Danish sustainability criteria for biomass will affect the average CO_2 coefficient.

The net CO_2 emissions from the combustion of biomass generates a cost, which in this analysis is calculated by multiplying net emissions by the price of CO_2 allowances in the EU. The quota price is projected to be 59.1 €/tonne in 2030 and 88.7 €/tonne in 2040. With 35 kg of CO_2/GJ and the expected quota prices, internalising the cost of biomass CO_2 emissions will equate to an additional forest biomass price of 2.1 €/GJ in 2030 and 3.1 €/GJ in 2040.

With a value of 35 kg CO_2/GJ, the total CO_2 cost generated over the period 2020-2040 in the reference scenario in present value terms is €1.64 billion. This cost expresses the value of released carbon in forests and agriculture using the quota price. The carbon is released in what is referred to as the LULUCF (Land Use, Land-Use Change, and Forestry) sector.

In the reference scenario, almost 100 PJ of biomass is used in 2020, with the demand falling by approximately 20% towards 2030, and just under 60% towards 2040. If biomass CO_2 emission costs become internalised in energy companies' decision-making processes with the CO_2 quota price, the consumption of biomass in Denmark will, relative to 2020, instead be reduced by roughly 40% towards 2030, and 70% towards 2040. However, using less biomass for electricity and district heating production increases the energy sector's costs by €0.22 billion. Meanwhile, the cost of the carbon released in the LULUCF sector is reduced by €0.48 billion, thus resulting in a total savings of €0.26 billion compared to the reference scenario. Note that all figures are in present value terms covering the period 2020 - 2040.

The scenario with less biomass demand is assessed to be technically possible, but it places considerable demands for rapid deployment of different types of heat pump systems for district heating production. The cost of doing so is calculated based on the assumption that new heat pump systems for the most part can be established close to existing district heating infrastructure. If this proves to be a challenge in practice, particularly in large cities, the cost of switching to heat pumps may prove to be higher than calculated.

In the above scenarios it is assumed that biomass plants cannot be scrapped before the end of their technical life. Nevertheless, if earlier scrapping in the period 2025-2030 is possible, biomass use will be further reduced, and total costs reduced by an additional DKK 0.8 billion during the period. Whether early phasing out of existing biomass plants in the period 2025-2030 is technically feasible is an issue that will require further clarification.

The calculated costs in the LULUCF sector are estimated to be real costs that will be imposed on the global community if the objectives and intentions of the Paris Agreement are pursued. When forests and fields release carbon to the atmosphere due to the demand for biomass from Danish electricity and district heating plants, this carbon loss must be compensated in other sectors if the climate target is to be maintained. Under the current framework, forests are typically operated without consideration of the direct economic impacts of the biogenic carbon pool.

An additional analysis of investments in carbon capture and storage (CCS) for waste incineration plants has also been undertaken. The possibility of implementing CCS in industry or at biomass-fired plants is however not included in the additional analysis. It is estimated that the CO_2 price will have to rise to well over 135 €/tonne before CCS on biomass-fired plants is socio-economically more attractive than reducing biomass use.

Perspectives

This work has not specifically analysed how best to internalise the effect of CO_2 from biomass, but the following options could be considered:

i. Include an emission factor of 35 kg CO_2/GJ wood biomass and 15 kg of CO_2/GJ straw in the socio-economic calculation assumptions, unless better data can be demonstrated for the specific project.

ii. Internalisation of the CO_2 effect through the price of biomass, for instance via a tax. The challenge here is that there is a big difference in the CO_2 effect of different biomass types. Certain types of residues from forestry and the wood manufacturing industry will for example have to be disposed of nonetheless, and therefore have low CO_2 coefficients, while other biomass types will have high coefficients.

iii. Politically decide on a limit for the combustion of biomass and the establishment of a system of combustion quotas with decreasing quota distribution over time. This approach has similar challenges with different biomass types as above.

iv. Establish a pricing system by building on existing LULUCF regulation. The existing regulation sets strict requirements for member states to maintain an inventory of their biogenic carbon pool starting from 2021. As a part of this, default half-life values for wood for different purposes have been determined. The standard half-life value is 0 years for wood for energy, 2 years for paper, 25 years for wood panels, and 35 years for sawn wood. By linking the LULUCF sector more closely to other climate legislation, forest owners can internalise the CO_2 value themselves in their pricing of the forest's various products based on forestry best practices. It will be a task to define an appropriate baseline for forest CO_2 balance that provides a reasonable earning opportunity for forests that act in a climate-wise manner.

v. Tighten sustainability requirements for biomass, possibly based on the new stricter registration requirements in the LULUCF Regulation.

vi. Develop a heat pump strategy that can accelerate the expansion rate of large heat pumps by hedging risks, experience collection, etc.

vii. Combinations of the above.

2 Summary

Since the 1990s, a large part of Danish electricity and heat production has been diverted from coal, largely to biomass and natural gas. At the same time, there has been a considerable expansion of both decentralised natural gas-fired CHP plants, and straw and wood chip-fired boilers in the small and medium-sized district heating areas. This development has largely been the result of the policy framework in the form of taxes on fossil fuels for space heating and various subsidy options for electricity generation based on renewable energy and decentralised cogeneration.

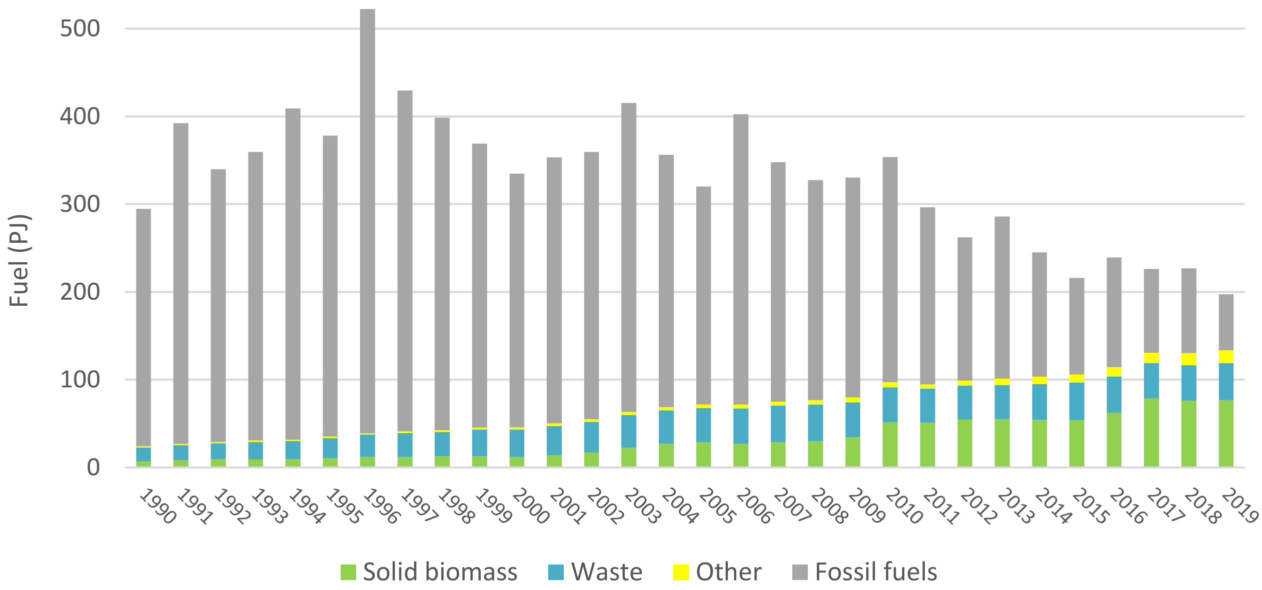

Figure 1: Development of fuel consumption for electricity and district heat production 1990 - 2019.

The consumption of fossil fuels, at the beginning of the period in particular, was linked to condensing electricity generation at large central power plants. In recent years, coal-based electricity generation has increasingly been replaced by wind and solar, as well as heat bound electricity generation based on biomass. Consumption of solid biomass has increased from approx. 10 PJ in 2000 to just under 80 PJ in 2019, and has increased further towards 2020 after the commissioning of new biomass cogeneration capacity.[1]

The continued use of biomass to replace fossil fuels has been called into question in recent years. This is partly driven by new recognition of the CO_2 effect of burning

[1] Energy statistics for 2020 have not been published at the time of writing.

biomass, and partly because of the falling electricity generation costs for solar and wind.

Biomass is, in principle, a renewable energy resource. However, if it is not burnt, and the wood is instead used for other purposes or left to stand or lie in the forest, then some of the carbon within the wood will be bound for a number of years rather than emitted as CO_2. Therefore, when biomass is burnt this will in most situations result in a net emission of CO_2 (carbon release from the biogenic carbon pool). With the continuous combustion of biomass, the ongoing carbon loss will fade over time, until a new balance between forest and atmosphere is achieved.

2.1 Carbon emission effect of biomass in a 30-year time perspective

When assessing different climate measures against each other, an important factor is the selected time perspective.

In 2018, the UN Panel on Climate Change (IPCC) published the report "Global Warming of 1.5°C", which describes, among other things, reduction scenarios to meet the Paris Agreement's efforts to keep temperature rise below 1.5 degrees. In the report's four main scenarios, net zero global emissions must be achieved between 2050 and 2065, i.e., within 30 to 45 years, and then become negative.

In order to reach global net zero emissions in the period 2050-2065 and negative emissions thereafter, it is necessary that developed nations reach net zero by 2050 or earlier. Denmark and the EU, among others, have adopted net zero targets by 2050, while Sweden and Germany have net zero targets already by 2045. According to this schedule, where the large CO_2 reduction challenge lies within the next 10 to 40 years, it makes little sense to discuss whether biomass is nearly carbon neutral over a 100-year perspective. Based on this understanding the current analysis has selected a 30-year time perspective for assessing net carbon emissions associated with the burning of biomass.[2]

Half-life and carbon emission coefficient

The net effect of burning biomass rather than not doing so from a thirty-year perspective is defined in this report as the carbon emission coefficient of biomass. In the case of residual products without indirect effects and where the growth of

[2] When biomass is burned, carbon emissions happen immediately, while carbon emissions from alternative degradation are discharged over the following 30 years. This time lag (i.e., discounting) is not taken into account in the current analysis. As an alternative to a 30-year time span without discounting, a view of for instance 100 years could be taken, with the two emissions discounted so that the immediate emissions from combustion count for more than the subsequent uptakes in the forest. These are two different ways of expressing a time preference. With a 100-year time horizon and using the Danish Ministry of Finance's risk-free discount rate, the two methods result in 35 kg CO_2/GJ and 36 kg CO_2/GJ respectively. This difference is not considered significant.

the forest is not affected, the rate of decomposition of biomass determines the carbon emission coefficient. The decomposition rate is expressed as a half-life.[3]

Based on the previously mentioned report from IGN, a carbon emission coefficient of 35 kg CO_2/GJ has been calculated for the average biomass used in a series of Danish biomass-fired plants over a number of years. The carbon emission coefficient corresponds to an average half-life of 20 years if the biomass is considered genuine residual products. The relatively high calculated half-life is because not all of the utilised biomass described in the IGN report can be characterised as genuine residual products.

2.2 Analysis methodology and results

The analyses were carried out via calculations with the Balmorel electricity and district heating market model.[4] The consequences associated with net carbon emissions from biomass have been analysed by establishing a reference scenario where the carbon emission coefficient of biomass is set to zero, thus corresponding to current inventory accounting methods, and a number of scenarios where the carbon emission coefficient of the wood biomass varies from 25 kg CO_2/GJ to as much as 50 kg CO_2/GJ.

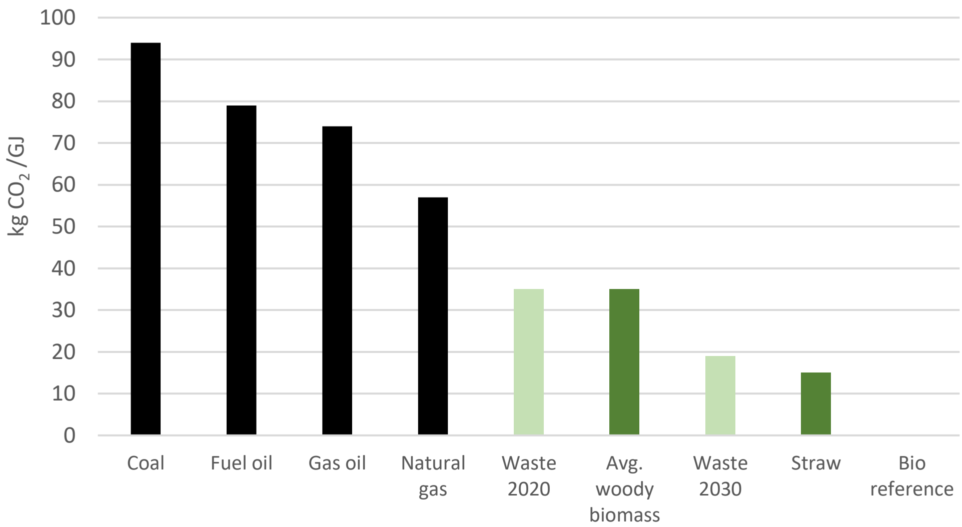

Figure 2: Carbon coefficient for different fuels used in the analysis. Waste 2030 is based on the Danish authorities' projection including measures for sorting out plastics and wet biomass from waste suitable for combustion. Avg. wood biomass is based on average data from the IGN report.

[3] The half-life of biomass is the time it takes for half of the biomass's carbon to be converted into CO_2. The half-life depends both on the specific characteristics of biomass and on its alternative use, e.g., decomposition in the forest floor.

[4] For further details on the model and analysis methodology, please refer to the report: "Potentialet for nye teknologier i el- og fjernvarmesektoren", prepared by Ea Energy Analyses in 2021. For an overview of updated input data, see the description of the main assumptions in the current report "Optimeret biomasseanvendelse til el- og fjernvarmeproduktion mod 2040".

Note that for straw, carbon emissions are zero in the reference and 15 kg CO_2/GJ in other scenarios, an assumption which is based on the report "Biogas og andre VE brændstoffer til tung Transport", by Ea Energy Analyses & University of Southern Denmark, 2016.

Reference development for the electricity and district heating sector

The figure below illustrates district heating production in Denmark in the reference scenario towards 2040. Heat production from heat pumps will increase significantly from a rather low level in 2020, to roughly 26% of district heating production by 2025, and nearly 58% by 2040. Initially, it is predominantly heat production from natural gas that is displaced by heat pumps, while biomass heat production is gradually reduced by 2040. Excess heat from PtX[5] is not explicitly simulated, but it can in practice replace a portion of the heat from heat pumps depending on future PtX frameworks.

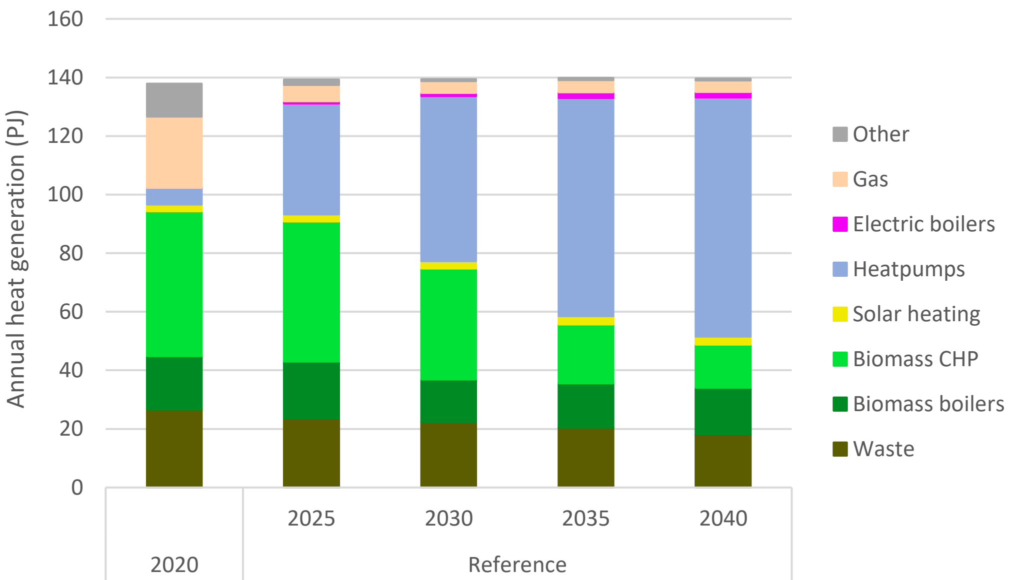

Figure 3: Annual district heating production for Denmark. Modelled for the reference scenario.

With respect to electricity production, considerable investments are undertaken in wind and solar power capacity in the reference scenario. Despite significantly higher electricity demand, dispatchable generation capacity will be reduced to roughly 4,000 MW by 2030 and 2,500 MW by 2040. The necessary balance in the electricity system during all hours is delivered via flexible operation of electrolysis systems, electric boilers, heat pumps, and not least via electricity exchange with

[5] Power to X (PtX) is a generic term for technologies, via electrolysis and possibly chemical synthesis processes, convert electricity into liquid or gaseous fuels. Some PtX processes produce heat that can be used for district heating.

neighbouring countries through both existing and new international connections. Flexible charging of electric vehicles and battery technology can also provide a smaller contribution to maintaining system balance.

Other scenarios

As mentioned above, in addition to the reference scenario, several scenarios have been established in which biomass is assigned a positive carbon emission coefficient to internalise the effects in the LULUCF sector. The effects in the LULUCF sector are factored into the analysis with the CO_2 quota price in the EU quota market. The quota price is projected to rise from 30.3 €/tonne in 2020 to just under 53.7 €/tonne in 2021, 59.1 €/tonne in 2030 and 88.6 €/tonne in 2040.

The figure below displays the development of biomass consumption for electricity and district heating production in all of the scenarios. In the reference scenario, there is a gradual reduction in biomass use as existing biomass plants reach the end of their technical life and are therefore phased out by the model.

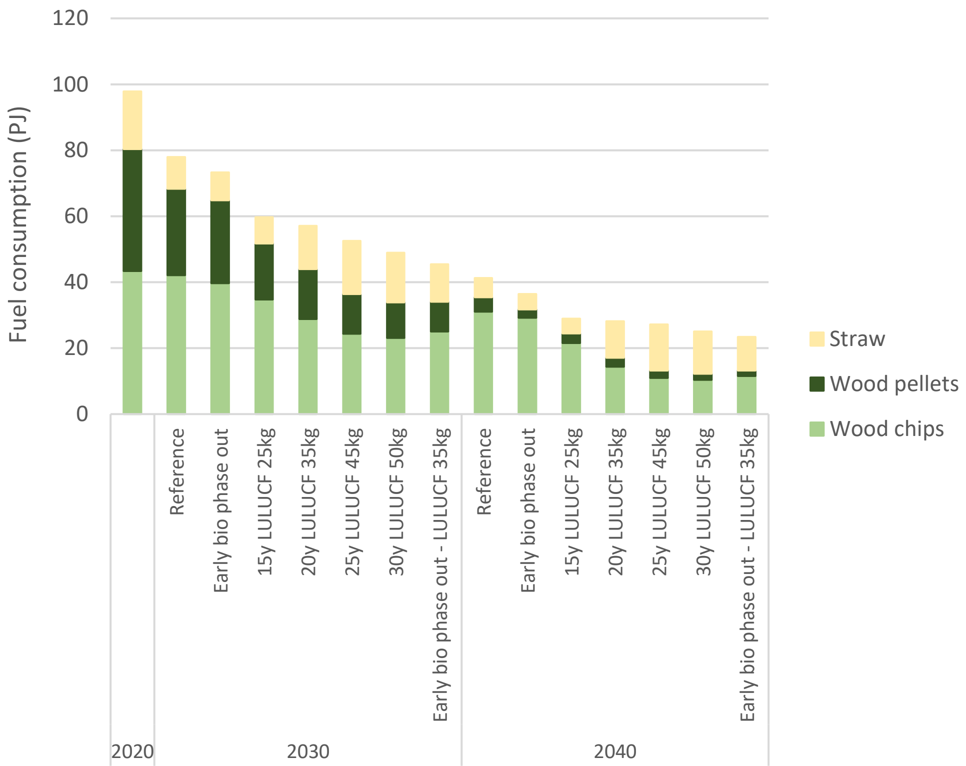

Figure 4: Development of biomass consumption for electricity and district heating production in Denmark.

Explanation: 15-year LULUCF 25 kg means that the LULUCF effect in this scenario is calculated as residual biomass with a half-life of 15 years, giving a carbon emission coefficient of 25 Kg CO2/GJ. In the early bio phase-out scenario, existing biomass plants can be phased out before the end of technical life. Early bio phase out – LULUCF 35kg is a combination scenario.

In the reference scenario, almost 100 PJ of biomass is used in 2020, with this demand decreasing by approximately 20% towards 2030 and just under 60% towards 2040. This is a slower rate of reduction than was found in previous analyses carried out by Ea.[6]

With the pricing of net carbon emissions from biomass in the LULUCF scenarios, biomass use relative to 2020 will be significantly reduced going forward, by roughly 40% towards 2030 and 70% towards 2040. Straw's share of total biomass consumption will be significantly higher in some scenarios. This increased straw utilisation is due to a lower net carbon emission from straw, as the reference for straw is ploughing, which has a shorter half-life. If the reference is instead alternative uses of the straw, for example biogas, or carbon storage, then both the price and carbon emission coefficient will change and the model result leading to increased straw use for combustion could be challenged.

In scenarios where the model is allowed to close biomass plants relatively quickly (in practice during the period 2025-2030), biomass use is reduced more significantly, especially towards 2030. This has positive economic impacts as it is plants with fewer operational hours that are closed. Whether the early phaseout of existing biomass plants during the period 2025-2030 is technically possible is an issue that will require further clarification.

Economics

If the consequences of the LULUCF sector are not included in the decision-making process for future investments in electricity and heat production plants in Denmark, the model analyses show that significantly more biomass is used than is economically rational. With a carbon emission coefficient of 35 kg CO_2/GJ biomass, the present value cost related to the LULUCF sector in the reference scenario for the period 2020-2040 is €1.64 billion. Under the UN and EU frameworks, carbon emission effects are imposed on the countries where the biomass is sourced from, and thus Denmark's share of the socio-economic LULUCF cost will be limited to that from domestic biomass.

The following table displays the economic impacts of the LULUCF scenarios compared to the reference. The results are shown both with and without quota costs from the LULUCF sector.

---

[6] This is due to updated and lower biomass prices, a more conservative expectation of the energy efficiency and economy of heat pumps, surplus heat from PtX not being explicitly counted - and finally, a larger demand for district heating.

Socioeconomics (NPV)	Early bio phase out - LULUCF 0kg	15 years LULUCF 25kg	20 years LULUCF 35kg	25 years LULUCF 45kg	30 years LULUCF 50kg	Early bio phase out - LULUCF 35kg
Biomass CO_2 cost in reference scenario, assuming biomass is not zero CO_2 (billion €)	-	1.21	1.64	2.08	2.34	1.64
Total cost in scenario (billion €)	**-0.03**	**1.07**	**1.38**	**1.62**	**1.77**	**1.25**
- Of which LULUCF of biomass (billion €)	-	0.95	1.16	1.28	1.39	1.03
- Of which Denmark's electricity and district heating sector (billion €)	-0.03	0.12	0.22	0.34	0.39	0.22
Total savings (billion €)	**0.03**	**0.14**	**0.26**	**0.46**	**0.56**	**0.38**
Biomass savings during the time period (PJ)	**42**	**169**	**193**	**229**	**260**	**251**
Average total savings of reducing biomass usage (€/GJ biomass reduced)	0.8	0.8	1.3	2.0	2.2	1.5
Average sector-cost of reducing biomass usage (€/GJ biomass reduced)	-0.8	0.7	1.1	1.5	1.5	0.9

Table 1: Resulting change in costs in the scenarios relative to the reference scenario. Present value 2020-2040 in billions of Euro. (LULUCF costs are calculated via the given emission coefficient in each of the scenarios). The dotted line reflects the central scenario involving a carbon emission coefficient of 35 kg CO_2/GJ biomass

For the time period 2020-2040, the present value of the additional socio-economic costs for Denmark's electricity and district heating sector in the LULUCF scenarios is calculated to be between €0.12 billion and €0.39 billion. The cost is primarily linked to the fact that some existing heat production plants which have not yet reached their technical lifetime, are not used, which is particularly true in several medium and large district heating areas.

With a carbon emission coefficient of 35 kg CO_2/GJ biomass, the present value of the additional cost to the Danish energy sector of reducing biomass faster than in the reference scenario is estimated to be 1.1 €/GJ phased out biomass.

If the net carbon emission from biomass is to be properly internalised, then the carbon emission effect in the LULUCF sector must be expressed in the price of biomass. With a carbon emission coefficient of 35 kg CO_2/GJ biomass, and a quota price of 59.1 €/tonne CO_2 in 2030 and 88.7 € in 2040, this essentially means a price increase of 2.1 €/GJ biomass in 2030 and 3.1 €/GJ biomass in 2040.