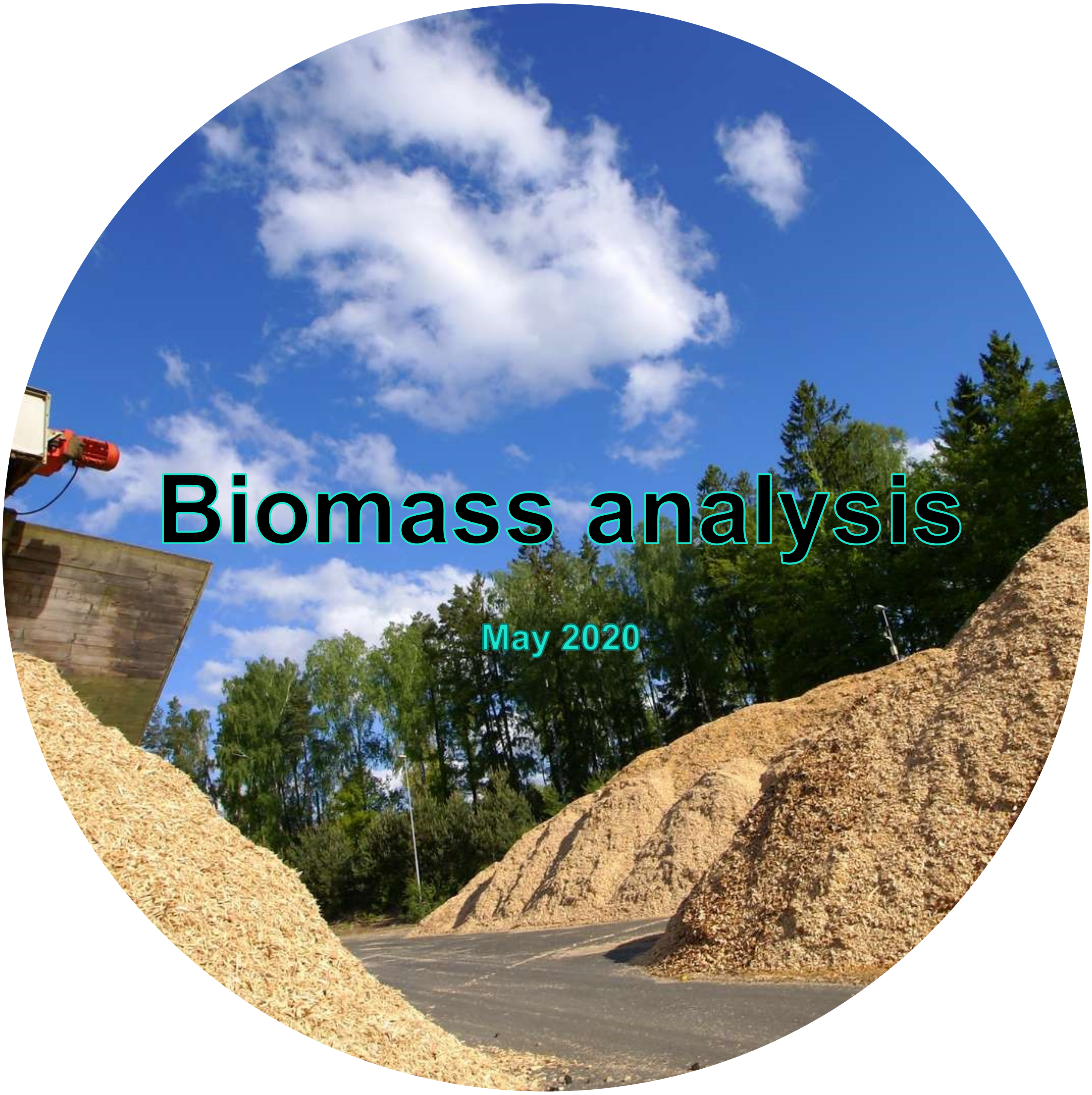
Danish Energy Agency



Biomass analysis

May 2020

Introduction

In August 2019, the Intergovernmental Panel on Climate Change (IPCC) published its Special Report on *Climate Change and Land*[1], among other things addressing the use of biomass for energy. The report raised debate about whether the use of biomass for energy purposes in Denmark is sustainable and CO_2 neutral.

This occasioned a biomass analysis by the Ministry of Climate, Energy and Utilities.

The analysis describes Danish consumption of solid biomass for energy, existing framework conditions and related issues concerning the resource base and sustainability. The climate impact, i.e. the impact of biomass consumption on the content of CO_2 in the atmosphere, is an essential aspect of sustainability and the main focus of this report. However, sustainability also comprises other aspects such as biodiversity and social effects, and these are also briefly addressed. The analysis focuses in particular on woody biomass for heat production alone and for combined heat and power (CHP) production.

Bioenergy is a broad term, many aspects of which have not been addressed in this report. This includes the use of biomass for biogas, biofuels and gasification, use of woody biomass for other purposes than energy such as to make building materials, furniture and other wood products, or biomass in a broader bioeconomic use of resources as well as alternative electricity production technologies. The possibilities for future use of woody biomass for other purposes than burning, however, is of significance for the conditions for using biomass for electricity and heat production, because woody biomass is a limited resource.

1.1 Main conclusions

Solid biomass in the form of wood, straw and biodegradable waste accounted for 64% of renewable energy (RE) used in Denmark in 2018. Straw, wood pellets and wood chips have largely replaced coal in the electricity and heat sector. In addition to this, woody biomass is used in individual heating systems and for industrial processes in manufacturing companies. In 2018, wood accounted for 75% of solid biomass, while biodegradable waste and straw accounted for 13% and 12%, respectively. More than half of woody biomass used in Denmark is imported from abroad.

International climate impact accounting rules

Increased use of biomass for electricity and district heating production is responsible for much of the reduction in greenhouse gas emissions from 1990 to 2017 in Denmark's national greenhouse gas inventory, as emissions from burning woody biomass are set at zero pursuant to international rules.

According to these rules, total national greenhouse gas emissions should be calculated as the sum of emissions from the different sectors. Emissions from burning biomass are not included in energy sector emissions but are instead included in the emissions from the so called LULUCF (land use, land use change and forestry) sector in the country where the biomass is harvested. The LULUCF sector can contribute with net emissions if the carbon stocks in soils and forests decrease, e.g. due to deforestation or if forest harvesting exceeds forest growth, or with net removals if the carbon stocks in soils and forests increase, e.g. due to afforestation or if forest growth exceeds forest harvesting. Emissions from biomass are therefore accounted for in the country that harvests the biomass and not in the country that uses the biomass.

[1]Climate Change and Land, An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. IPCC, August 2019.

Denmark calculates emissions and removals from LULUCF and accounts them towards the 70% target set in the Danish Climate Act. In years when more biomass is harvested for energy than trees and plants produce as they grow, Denmark will register emissions, potentially making it more difficult to achieve the 70% target. If less biomass is harvested than the growth in biomass, this will be registered as removals, potentially making it easier to achieve the target.

For biomass imported to and burned in Denmark, any emissions should be included under the LULUCF sector in the country where the biomass originated. These emissions are therefore not included in Denmark's greenhouse gas inventory and can therefore not help meet the Danish target. Where the biomass harvested has reduced the total carbon stock or CO_2 removal of forests in the country of origin, this will have led to emissions globally. If the country of origin represents these emissions truly and fairly and balances them against a binding and adequate mitigation target, these emissions could be offset by reductions in other sectors.

Several countries currently have no binding mitigation targets (NDCs) or do not include LULUCF sector emissions in any targets they may have. These include Russia and the US, which in 2018 together supplied around one quarter of the biomass imported by Denmark for energy purposes. Different LULUCF guidelines, different calculation methodologies and different interpretations of the complex technical basis moreover make it difficult to determine and check whether emissions from the LULUCF sector are being represented fairly in inventories.

It can therefore be concluded that although international guidelines allow for the consumption of biomass by the energy sector to be counted as zero emissions in Denmark, there is a risk Danish biomass consumption by the energy sector causes emissions globally.

National initiatives could also in other areas, e.g. the ETS sector and agriculture, lead to global reductions being smaller than the reductions estimated nationally (what is known as 'carbon leakage'). This report does not examine this in more detail.

The climate impact of biomass
It is difficult to calculate the total climate impact of burning biomass across sectors, and it would require a data basis that is currently not publicly available. This analysis has not calculated the global climate impact of biomass consumption by the Danish energy sector.

International studies show that the climate impact of using forest biomass for energy varies. The impact depends on a number of factors, including the magnitude of consumption. The higher the consumption of biomass for energy, the greater the risk that this use of biomass will lead to a high level of emissions. Other important factors include: the type of biomass used, forest management practices, market effects and time perspective. Furthermore, the impact depends on the alternative use of land and biomass, as well as on the type of energy source replaced by biomass.

Forest residues, thinnings, industrial wood residues and waste wood are generally associated with a low level of emissions, as these types of biomass would typically have decayed anyway over a short period of time, thus releasing CO_2. For large tree trunks, tree stumps and roots, emissions may be higher - and may for a period even be higher than for the fossil alternative. The period when emissions from harvesting and burning biomass may be higher than for the fossil alternative may vary from under a year to several hundred years. After this time, the additional emissions could be more than offset by additional removals by replanted new, younger and faster growing forest trees, and the climate impact could be positive, depending on what the harvested biomass is used for in addition to energy.

This analysis shows that, in overall terms, the use of biomass for energy in many cases benefits the climate, e.g. when residues replace fossil fuels. Other situations, e.g. cutting down large trees for energy production without replanting new trees, can contribute more to climate change than if coal had been used instead.

A detailed calculation of the climate impact of biomass requires accurate definition of the system analysed and the biomass used, the relevant time period and the alternatives. There is currently no accessible data basis for calculating the real, overall climate impact of using biomass for electricity and heating in Denmark.

The size of the biomass resource

Globally, 2017 saw the consumption of 37.3 EJ solid biomass for energy. The size of the sustainable bioenergy potential has been assessed at between 100 and 300 EJ[2]. The UN IPCC has assessed that by 2050 the global sustainable bioenergy potential will be limited to around 100 EJ per year, and only some of this potential will be in woody biomass. Such an estimate, however, is associated with considerable uncertainty. According to the IPCC, consumption at or above this level may put considerable pressure on available land, food production and prices as well as on preservation of ecosystems[3]. A maximum potential of 100-300 EJ biomass corresponds to 10-30 GJ per person per year in 2050. In 2018, Danes consumed around 27 GJ biomass per person for energy, of which around 20 GJ was woody biomass.

The maximum energy potential of biomass and biogas produced in Denmark is assessed in the short term to be around 160-180 PJ, including biodegradable waste but excluding energy crops and so-called blue biomass in the ocean. A potential of 180 PJ corresponds to around 31 GJ per Dane, of which no more than around 10 GJ is estimated to be woody. If land is designated for the cultivation of crops or wood for energy, the potential will be greater, however this will require replacing land used in production of food products or fodder, and this could have indirect land use change impacts.

Requirements for the sustainability of biomass fuels from forestry

There are currently no legal requirements for the sustainability of biomass used for energy. Rather, in 2014, a sector agreement was established voluntarily on the sustainability of wood pellets and wood chips for electricity and district heating in Denmark. A new EU Renewable Energy Directive (Renewable Energy Directive II, RED II) includes minimum requirements for the sustainability of biomass fuels from forestry. The new directive is to be implemented into Danish law by no later than 30 June 2021.

In a number of areas, sustainability requirements, such as requirements for forest regeneration and requiring that the country of origin is a party to the Paris Agreement and that it includes the LULUCF sector when calculating its progress towards achieving its mitigation target, etc., could address the sustainability-related challenges of using biomass for energy.

Framework conditions and alternative technologies

Framework conditions so far in Denmark have led to considerable consumption of biomass for CHP and district heating production. Conversion of large-scale CHP plants from fossil fuels to biomass has been promoted through state aid for electricity production based on biomass (the *15-øren* (DKK 0.15) scheme), tax exemption for biomass as opposed to electricity and fossil fuels, and the possibility to use tax benefits to reduce electricity production costs (the net benefit model). The latter was introduced with the 2012 Energy Agreement.

Several large-scale plants have therefore converted from coal-based to biomass-based production, and six units have been converted or established since 2012. The transition from coal to biomass corresponds to heat production of around 8,500 TJ in 2018. Furthermore, Amagerværket and Asnæsværket changed from coal to wood chips in 2019 and 2020, respectively. As a result of the

[2] Analysis of bioenergy in Denmark, Danish Energy Agency 2014.

[3] IPCC: 2018 Global Warming of 1.5°C. An IPCC Special Report.

extensive conversion of large-scale power plants from coal to biomass in recent years, only three fully coal-fired CHP units exist in Denmark today.

The 2018 Energy Agreement gives the smallest small-scale CHP plants opportunity to establish electric heat pumps or biomass boilers if necessary, to safeguard against higher heat prices. This is regulated through a requirement for approval of biomass projects on the basis of the financial consequences of the project for consumers. In smaller district heating areas, electric heat pumps - possibly in combination with solar heating - are typically a competitive alternative to existing systems based on biomass or natural gas, which typically cover most of the annual heat production. To meet the increased heating demand in winter, CHP/heating plants can use units that run on biogas, bio oil, electricity or biomass.

In most of the larger small-scale district heating areas and in the large-scale district heating areas, current regulations do not allow for the establishment of plants producing just heat, such as biomass boilers. The phasing-out of coal-fired plants in the cities of Esbjerg, Odense and Aalborg and the associated possibility to apply for exemption from the cogeneration requirement raises a need to establish alternative large-scale, RE-based heat production. It is assessed that RE-based production will be based on biomass in these areas, as there are considerable challenges associated with meeting most of the annual demand for heat production through heat pumps. Among other things, this is due to limited land on which to exploit air and solar heat sources, as these technologies are very space-consuming; limited alternative heating sources; and limited experience with heat pumps on a very large scale. Relevant heat sources for large-scale heat pumps could be seawater, wastewater, surplus heat and geothermal energy.

Demand from individual heating systems for biomass in the form of wood pellets and firewood is similar to the demand from large-scale CHP plants. A large part of the firewood consumed is used as a supplemental heat source to natural gas, oil and district heating, while wood pellet boilers constitute an alternative to oil-fired boilers and natural gas boilers, in remote areas in particular.

Reading guide

Chapter 1 describes how biomass has been used for electricity and heat production in Denmark so far and how it is expected to be used in the future up to 2030.

Chapter 2 outlines current international rules on how to report emissions from use of wood for energy.

Chapter 3 describes the climate impact of using woody biomass for energy and briefly looks at other sustainability aspects such as biodiversity. Chapter 3 ends with a conclusion on the climate impact of biomass.

Chapter 4 looks at the size of the global and the national biomass resource, respectively.

Chapter 5 describes the sustainability requirements on biomass, including the requirements set out in the new EU Renewable Energy Directive, which will enter into force in 2021.

Existing and planned economic instruments targeting the use of biomass for electricity and heat production are outlined in chapter 6.

Chapter 7 maps the influence of current regulation in the heating area on the deployment of biomass.

Finally, chapter 8 describes alternative technologies for heat production for different types of district heating areas and for areas with individual heating systems.

1. Consumption of solid biomass for electricity and heat production in Denmark

This chapter describes the use of biomass in Denmark so far and how it is expected to be used in the future up to 2030. The chapter focuses on woody biomass in the form of wood pellets, wood chips, firewood and wood waste, however other types of bioenergy are also addressed: other solid biomass in the form of straw and biodegradable waste, as well as biogas and liquid biofuels.

1.2 Solid biomass in Danish energy supply

Solid biomass makes up the main part of renewable energy used in Denmark. In 2018, solid biomass made up 64% of total renewable energy consumption[4]. Figure 1 shows renewable energy consumption in 2018 by type of energy.

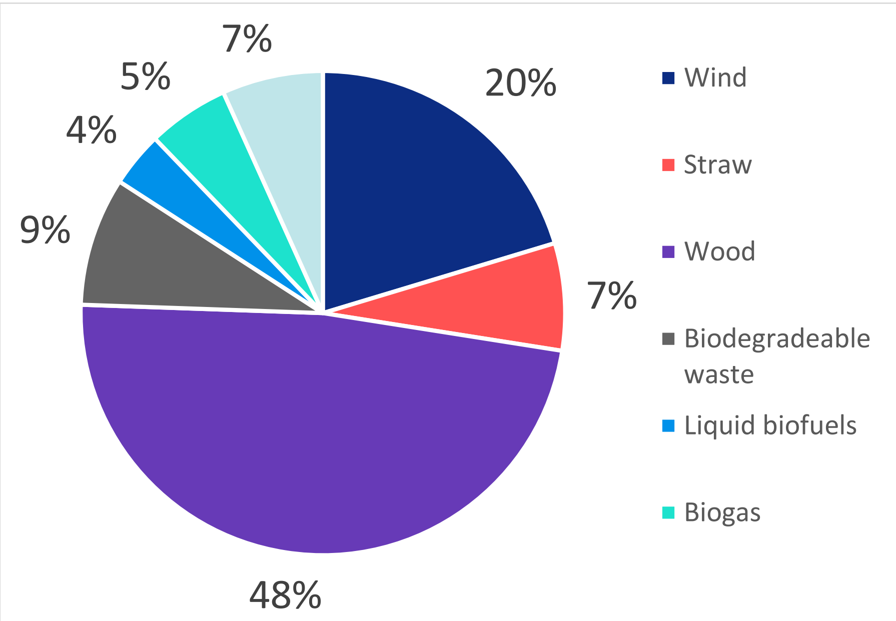


Figure 1. Consumption of renewable energy in Denmark in 2018, by type. Source: Energy Statistics 2018

In 2018, consumption of renewable energy[5] amounted to 246 PJ, of which solid biomass accounted for 157 PJ.

In electricity and district heating production, a total of 162 PJ was consumed, of which 67 PJ was from woody biomass, followed by wind power with 50 PJ and biodegradable waste with 20 PJ. Straw, biogas and other renewable energy accounted for 13, 6 and 6 PJ, respectively. See Figur 2.

[4] Solid biomass = wood pellets, wood chips, firewood, wood waste, straw and biodegradable waste.

[5] Production plus net imports.

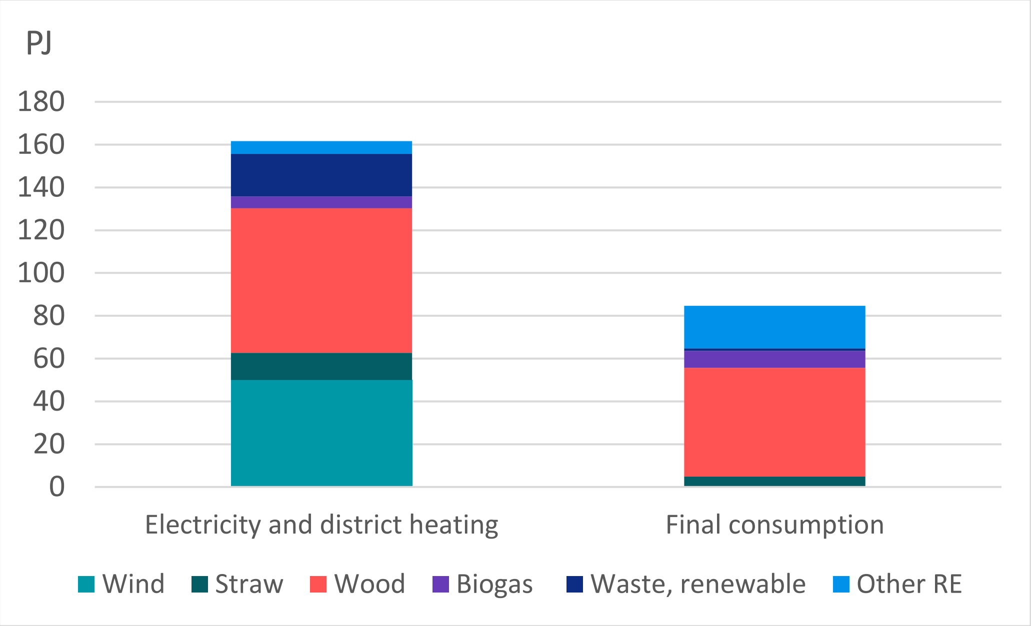


Figure 2 Use of renewable energy in 2018. Source: Energy Statistics 2018

In 2018, final energy consumption consisted of 85 PJ renewable energy[6]. Final energy consumption is the energy that is delivered directly to end users, i.e. private and public-sector enterprises and households, and which is used for process consumption, heating and transport. Woody biomass, in the form of firewood, constitutes the largest share in final renewable energy consumption.

Solid biomass has increasingly replaced the use of fossil fuels for electricity and heating. This transition has taken place over several years. Figure 3 illustrates the development in use of fossil fuels and renewable energy in Danish energy consumption from 1990 to 2018.

[6]Energy consumption for extraction, refining and conversion is not included in final energy consumption.

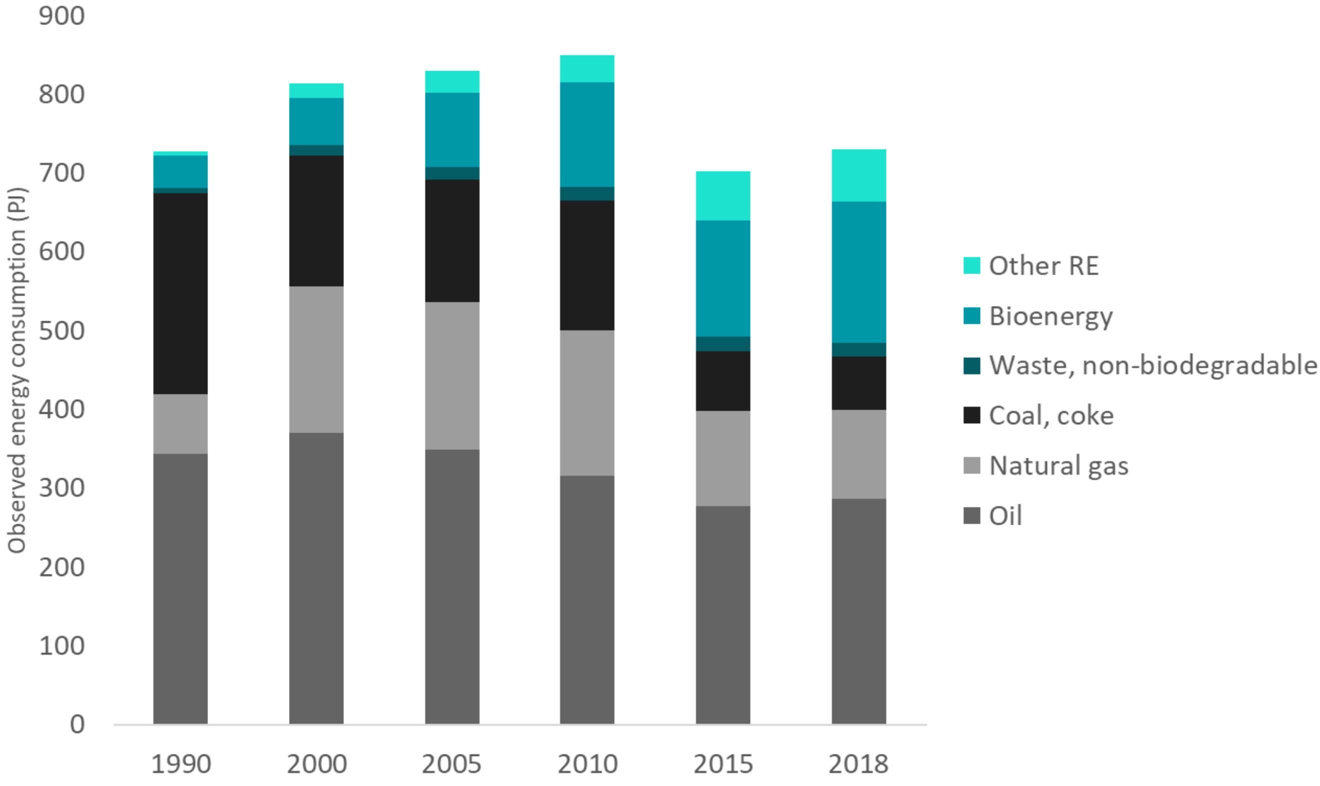


Figure 3 Energy consumption by fossil and renewable fuels stated as observed energy consumption 1990-2018. Source: Energy Statistics 2018

Up to 2000, waste, straw and firewood were the primary renewable fuel. In the period that followed, the use of wood pellets and wood chips in particular increased. Since 2010, wood pellets have been dominant in the consumption of solid biomass for energy purposes. Wood pellets are used in existing coal plants for co-firing (as support fuel) or in coal plants that have been converted to fire with wood pellets as the main fuel instead of coal. Figure 4 shows the development in the consumption of the various types of solid biomass.

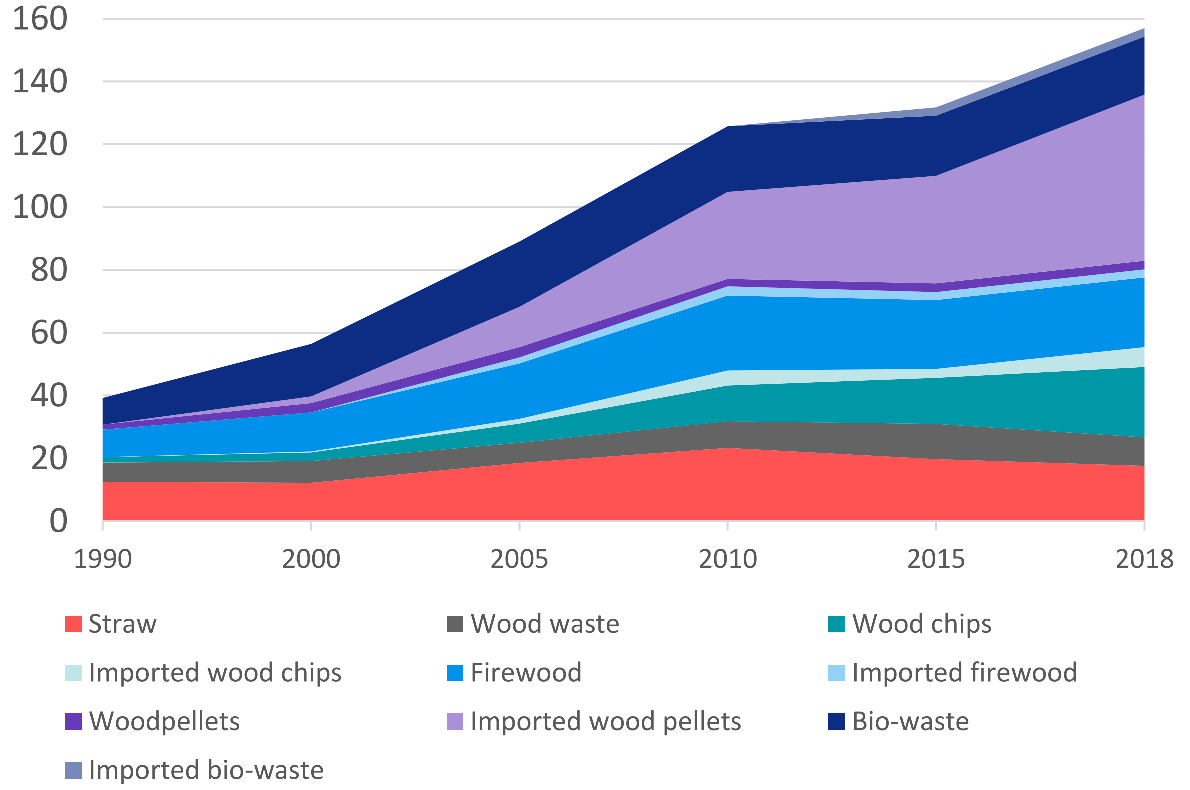


Figure 4. Development in biomass consumption in Denmark 1990-2018 (PJ). Note the uneven time intervals on the X-axis. Source: Energy Statistics 2018

Consumption of solid biomass for energy purposes in Denmark increased from just less than 40 PJ in 1990 to 157 PJ in 2018. Most (75%) of the solid biomass is woody biomass, of which most is wood pellets. In 2018, a total of 3.2 million tonnes wood pellets were used for energy in Denmark.

Solid biomass is an international commodity, and most of the wood pellets that are used in Denmark are imported from other countries and are used in both large and small systems. Smaller volumes of wood chips, firewood and biowaste are also imported. Figure 4 shows the development in the use of imported and domestic solid biomass for energy purposes. In 2018, 53% of woody biomass (wood chips, wood pellets, firewood and wood waste) and 95% of wood pellets were imported[7].

Consumption of wood pellets produced in Denmark has been relatively low over the past 20 years, while consumption of imported wood pellets has increased significantly. Consumption of imported wood chips has also increased but at a slower rate. Consumption of domestic wood for energy (wood chips, wood pellets and firewood) increased from 18 PJ in 2000 to 47 PJ in 2018. The imported wood chips are mainly used by large energy plants, while domestic energy wood today goes primarily to small-scale energy plants and to firewood.

1.3 Use of solid biomass in different sectors

CHP plants are the largest buyers of solid biomass for energy purposes. Of all wood used for energy purposes, 57% is used in collective electricity and heat production (electricity and district heating), 36% is used in individual heating systems (wood-burning stoves and wood pellet boilers), and the

[7] Danish Energy Agency Energy Statistics 2018.

remaining 7% is used in industrial processes in manufacturing companies. The use of solid biomass for various purposes is illustrated in Figure 5 and presented in Table 1.

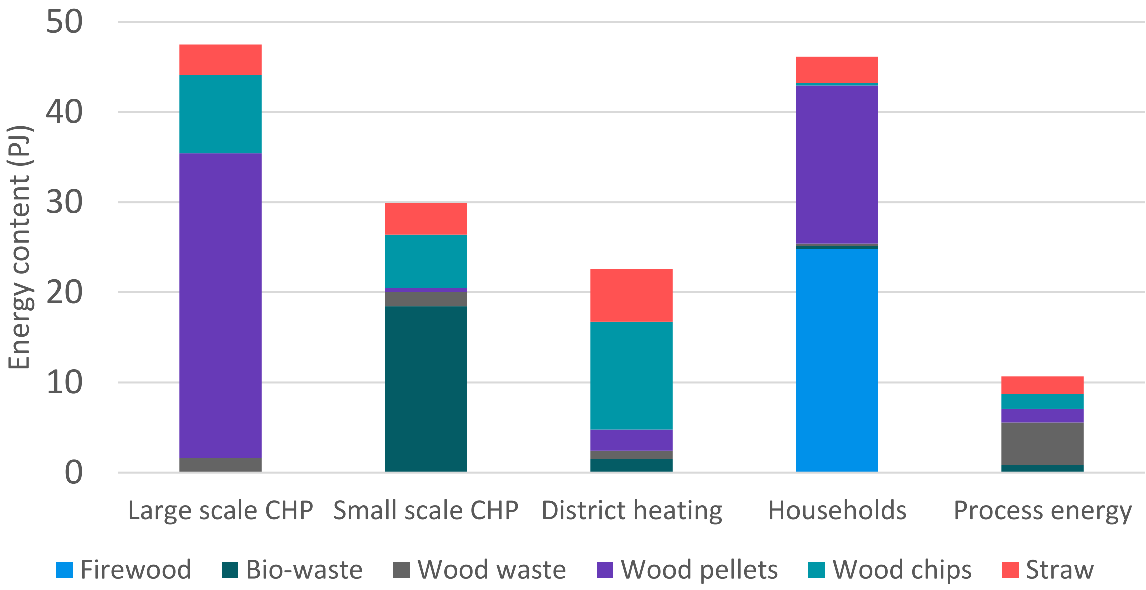


Figure 5 Use of solid biomass in collective electricity and heat production, individual heating systems and for process energy. Source: Energy Statistics 2018

Notes: Small-scale CHP plants + waste treatment facilities include autoproducers and agriculture and industry servicing the collective supply. Process-energy purposes covers agriculture and industry, e.g. agriculture and forestry and manufacturing industries. Large-scale CHP plants are CHP plants in large cities that, in addition to producing electricity, supply district heating to these cities. Waste incineration plants fall under small-scale CHP plants. District heating plants are plants that produce just heat.

	Large-scale CHP	Small-scale CHP	District Heating	House-holds	Process energy	Total
Wood chips	8.7	5.9	12.0	0.2	1.6	28.5
Wood pellets	33.8	0.5	2.3	17.5	1.5	55.7
Firewood	0.0	0.0	0.0	24.8	0.0	24.8
Wood waste	1.6	1.6	0.9	0.2	4.7	9.1
Bio waste	0.0	18.4	1.5	0.4	0.8	21.1
Straw	3.4	3.5	5.8	2.9	2.0	17.6
Total	47.5	29.9	22.6	46.2	10.7	156.8
%	30%	19%	14%	29%	7%	

Table 1 Energy consumption from biomass by sectors in 2018 (PJ). Source: Energy Statistics 2018

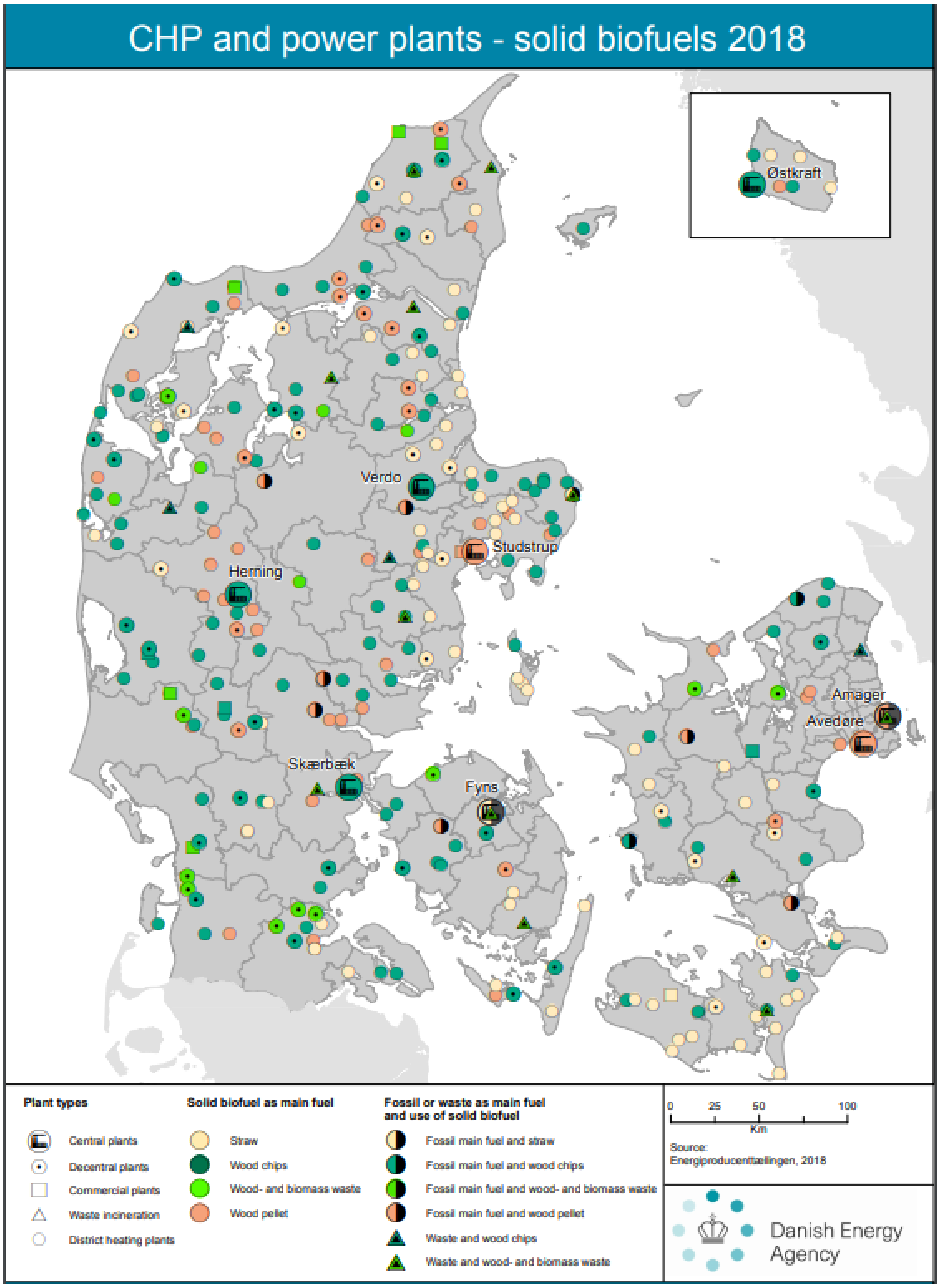


Figure 6 Map of CHP plants and heating plants running partly or fully on biomass.

As can be seen from the map in Figure 6, many small-scale CHP plants and district heating plants used solid biomass as their main fuel in 2018. Other plants use biomass as a supplemental fuel to fossil-fuel-based waste incineration.

Today, five large-scale plants use wood chips, some also straw, (Lisbjerg in Århus, Herning, Skærbæk, Verdo in Randers and Østkraft on Bornholm), and two large-scale plants use wood pellets, one of which also uses straw, (Avedøre and Studstrup). Amagerværket uses wood pellets and wood chips. Fynsværket uses straw and coal. Large-scale plants have seen a shift away from coal since 2012. Eight coal units have been replaced by seven biomass units, six of which were converted or established after 2012. The transition from coal to biomass corresponds to heat production of around 8,500 TJ in 2018. Furthermore, Amagerværket and Asnæsværket changed from coal to wood chips in 2019 and 2020, respectively.

1.4 Countries of origin for imported woody biomass

The majority, around 60%, of imported woody biomass comes from other EU countries, but a significant amount, almost 40%, comes from countries outside the EU[8].

Wood pellets are primarily imported from the Baltic countries, Estonia and Latvia in particular, as well as from the US and Russia. Smaller amounts are imported from Sweden, Portugal, Poland and Germany. Imports from the US increased significantly from 2016 to 2018 and counted 600,000 tonnes in 2018. The most important countries of origin for wood pellets in 2018 are shown in the figures below. “Other countries” includes Belarus and Ukraine, amongst others.

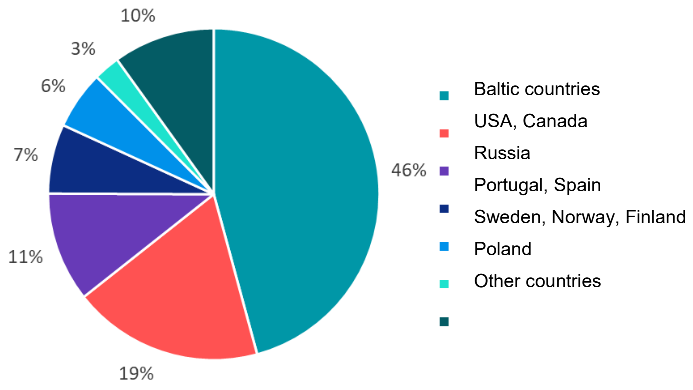


Figure 7 Country of origin for wood pellets imported to Denmark in 2018. Source: Statistics Denmark

There are a few Danish producers of wood pellets[9]. Production increased from 160,000 to 200,000 tonnes from 2016 to 2018. There are around 30 importers of wood pellets, and the 12 largest importers account for 91% of total imports. There are moreover parallel imports and unregistered border trade across the border to Germany, e.g. due to a more beneficial VAT rate in Germany.

Wood chips are imported from the Baltic countries, the Scandinavian countries, other EU countries and Russia. Wood chips are also imported from Brazil. In some situations, whole trunks are imported and then converted into wood chips in Denmark.

For wood pellets and wood chips overall in 2018, 43% came from the Baltic countries; 16% came from the US and Canada; 10% from Russia; 18% from other EU countries; and 12% from other non-EU countries.

[8]Statistics Denmark, Statbank Denmark 2019. The categories: firewood, coniferous; firewood, deciduous; conifer - wood chips; wood - wood chips; wood pellets; briquettes.

[9] ”Det danske træpillemarked 2018” (Mapping of the Danish wood pellet market in 2018), Ea Energianalyse for the Danish Energy Agency, October 2019.

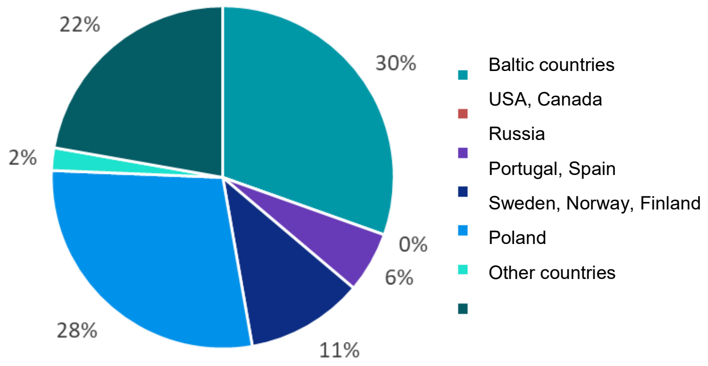


Figure 7 Country of origin for wood chips imported to Denmark in 2018. Source: Statistics Denmark

1.5 Denmark's Energy and Climate Outlook: Expected biomass consumption up to 2030

The Danish Energy Agency presents its expectations of the demand for biomass for energy in its Denmark's Energy and Climate Outlook (DECO) publication, which presents the expected consumption in the absence of new political initiatives. The expected demand for biomass for energy up to 2030 is shown in Figure 8.

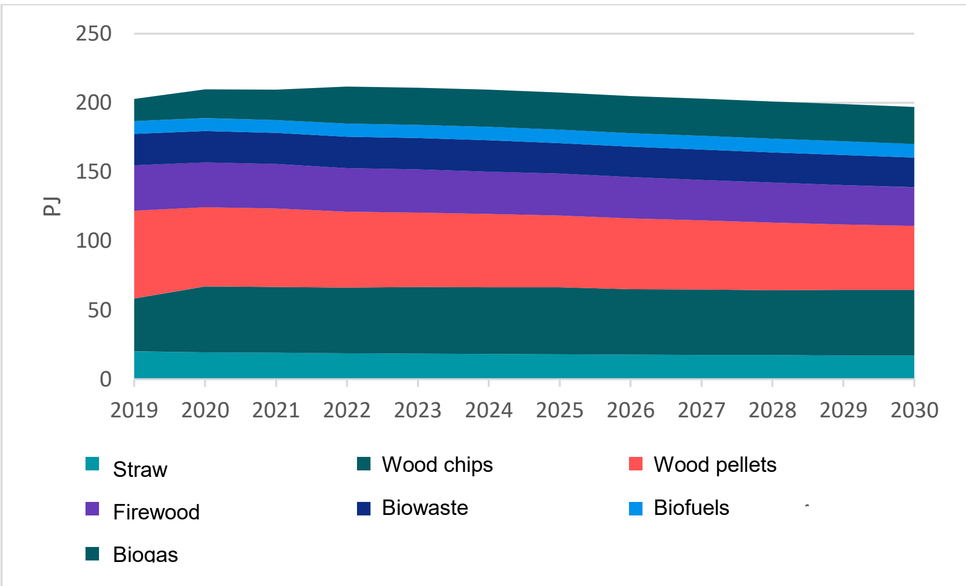


Figure 8 Projected bioenergy consumption up to 2030. Source: Denmark's Energy and Climate Outlook 2019 (DECO19).

Consumption of wood pellets increased up to 2018, while consumption of wood chips is expected to increase up to 2023. Consumption of wood pellets is expected to drop from 2020, while consumption of wood chips is expected to come to a standstill after 2023. Consumption of wood waste, straw and biodegradable waste will remain fairly constant, with only a slight downward tendency. Production of biogas is expected to increase significantly up to 2022 due to the ongoing major capacity expansion. After this time, production is expected to stabilise at 28 PJ:

In 2017, Danish power plants consumed 60.7 PJ coal. It is projected that around one-third of this will be replaced by renewable energy up to 2023. The largest producer of electricity and heating in Denmark, Ørsted, is in the process of converting its power plants from coal to biomass. Ørsted aims to have fully phased out coal by 2023 at the latest. HOFOR, which supplies electricity and heating to Copenhagen, is also in the process of phasing out coal. This will contribute to a continued fall in the demand for fossil fuels. The phase-out of coal has so far led to an increase in the consumption of biomass in Denmark, as can be seen in Figure 9. In future, demand for wind power, solar energy and heat pumps is expected to increase, while the demand for biomass will start to decline.

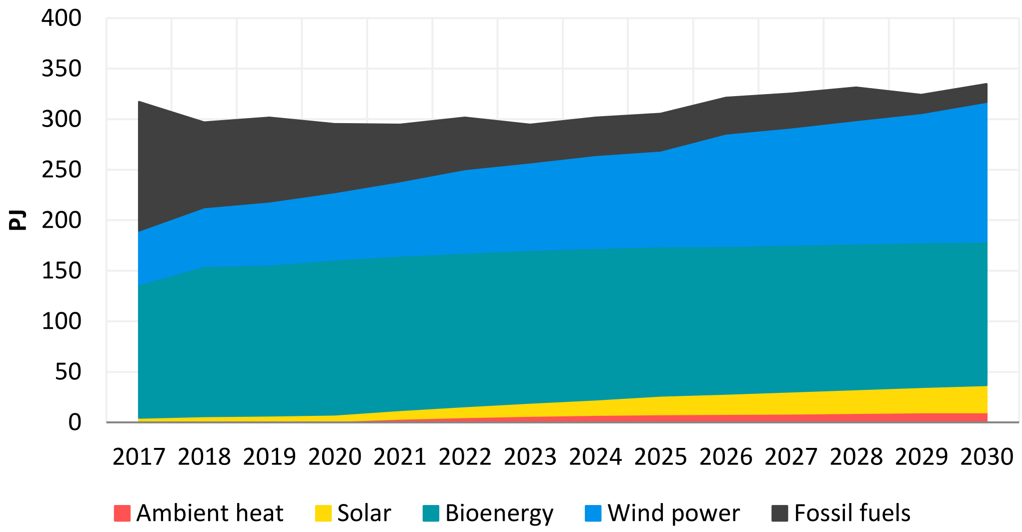


Figure 9 Energy consumption by the electricity and heat sector by main energy type 2017-2030 (PJ) Source: Denmark's Energy and Climate Outlook 2019 (DECO19).

Figure 10 shows the development in the district heating sector. The use of heat pumps is expected to increase gradually, and demand for natural gas for district heating is expected to fall. Production from heat pumps and electric boilers will increase by 15% annually, contingent on, among other things, a reduction in the tax on electric heating and phase-out of the PSO tariff. Heat pumps and electric boilers are expected to account for around 10% of total district heating production in 2030. Heat pumps cover production from ambient heat and surplus heat. Surplus heat is without the use of heat pumps.

Consumption of solar heating will increase by around 10% annually. Non-biodegradable waste is included in fossil fuels and will account for around 10% of district heating production in 2030.

On this basis, the renewables share in district heating (RES-DH) is expected to increase from 55% in 2017 to 76% in 2023, and then increase slightly to almost 80% in 2030. RES-DH will not reach a higher level, particularly due to the consumption of waste in district heating production and the fossil (non-biodegradable) share of this.

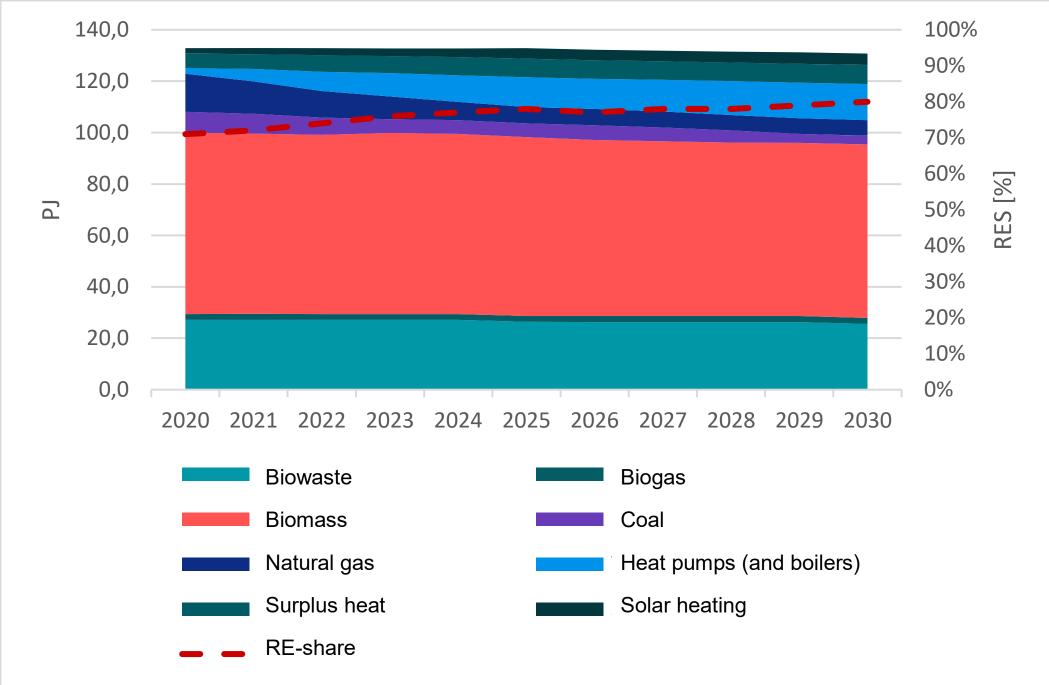


Figure 10 District heating production by type of energy 2017-2030 [PJ]. Source: Denmark's Energy and Climate Outlook 2019 (DECO19).

1.6 Expected electricity and heat production based on biomass up to 2030

The expected biomass consumption for district heating and CHP production in Denmark up to 2030 has been estimated on the basis of data on the individual energy plants from Denmark's Energy and Climate Outlook. All large-scale and small-scale CHP plants, waste incineration plants with biomass consumption as well as district heating boilers have been included in the estimate, i.e. all biomass consumption in Denmark for electricity and heating production has been included, except for consumption by individual heating systems. Plants that produce just heat are therefore also included.

Figure 11 shows the expected biomass consumption in TWh/year broken down by type of biomass (i.e. wood chips, wood pellets, wood waste and straw).

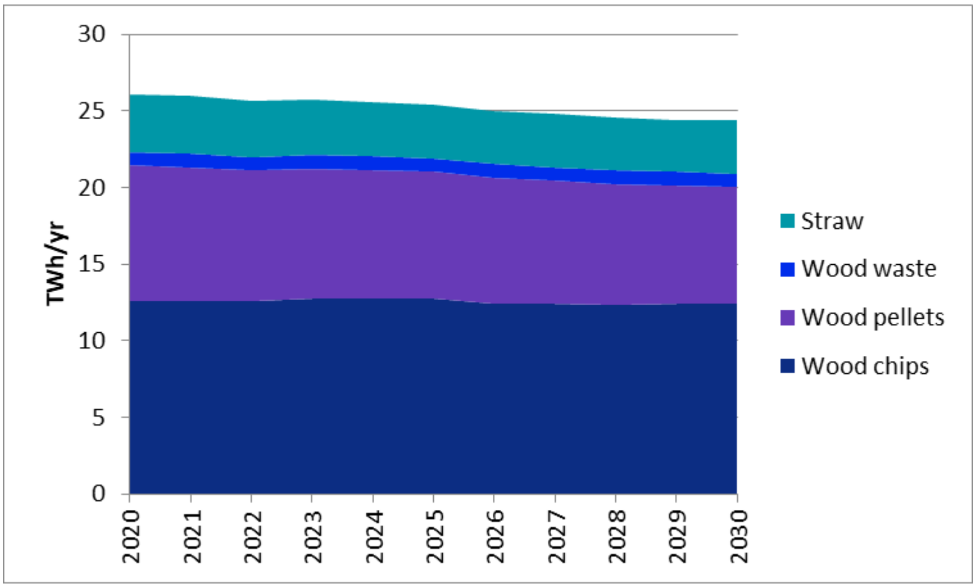


Figure 11 Expected biomass consumption in Denmark up to 2030 by type of biomass.

Figure 12 and Figure 13 show the size of the shares for straw and wood, respectively, in biomass consumption by large-scale and small-scale CHP plants and district heating boilers. As can be seen from the figures, straw is primarily used at small-scale CHP plants or in district heating boilers (around 75% of straw consumption), while wood is primarily used at large-scale plants (around 66% of wood consumption).

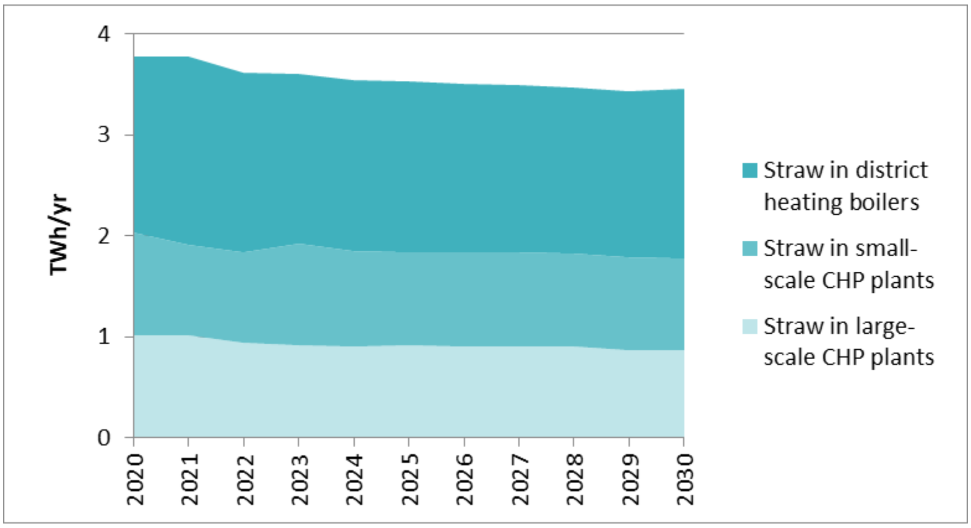


Figure 12 Expected straw consumption up to 2030 by large-scale and small-scale plants.

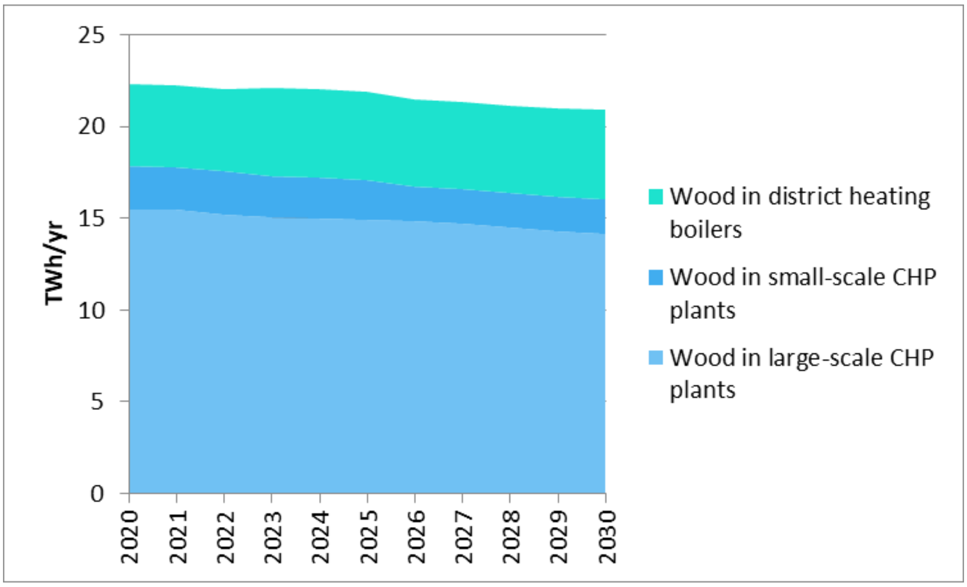


Figure 13 Expected wood consumption up to 2030 by large-scale and small-scale plants.

1.7 Biomass-fired plants: lapse of subsidies and expected time of write-off

Figure 14 shows expected wood consumption broken down by large-scale CHP plants. A few large power plants (e.g. Amagerværket, Avedøreværket and Studstrupværket) are responsible for a significant share of total woody/forest biomass consumption. Small-scale plants include small-scale CHP plants, waste treatment facilities and district heating boilers.

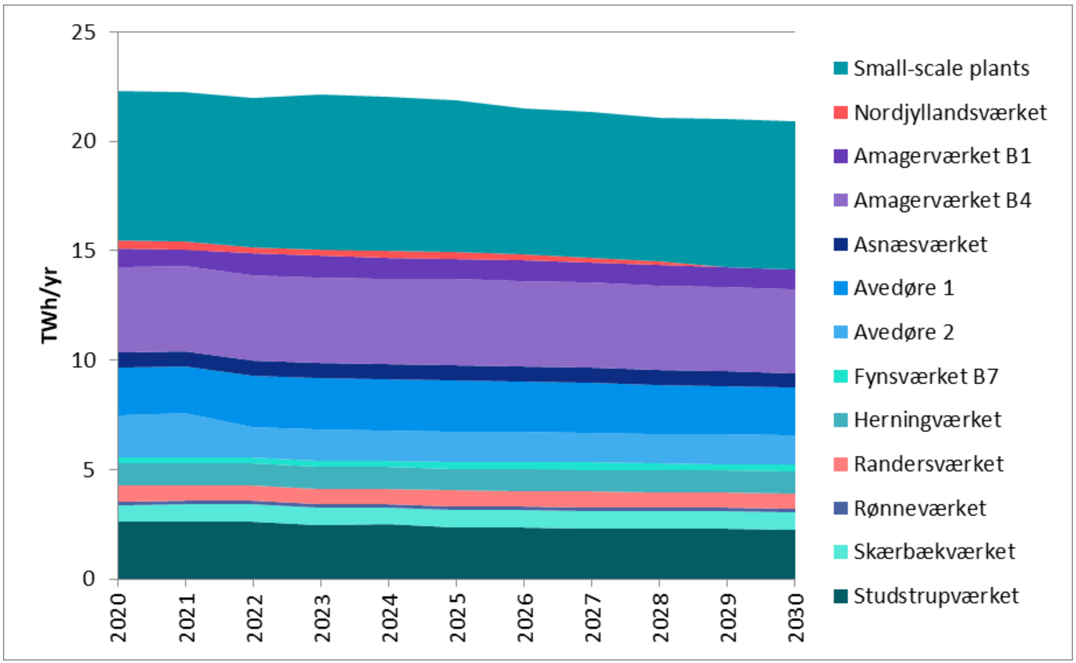


Figure 14 Expected wood consumption up to 2030 by large-scale CHP plants. Small-scale plants include both small-scale CHP plants, waste treatment facilities and aggregated boilers.

Figure 15 shows how biomass consumption in the form of wood for electricity and district heating production breaks down by district heating regions. The figure reveals that the large urban areas of Aarhus and Greater Copenhagen account for the main part of consumption.

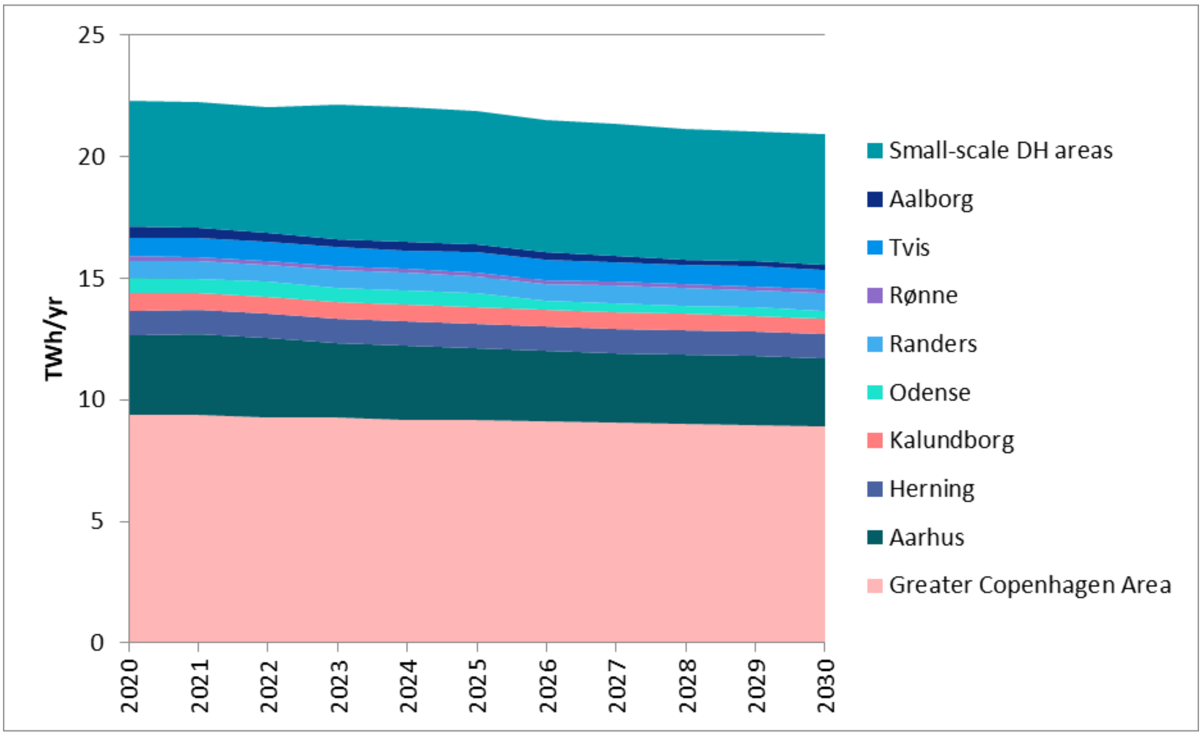


Figure 15 Expected wood consumption up to 2030 at large-scale and small-scale CHP plants by district heating region. Small-scale plants include both small-scale CHP plants, waste treatment facilities and district heating boilers.

Figure 16 shows the estimated energy production from woody biomass at large-scale CHP plants from 2020 to 2030 subject to the following assumptions:

a) That the plants cease production when the *15-øren* (DKK 0.15) scheme expires (dark-shaded areas), see chapter 6 on support schemes
b) That the plants cease production when service-life extension investments are needed, which typically coincides with the time of expiry of existing heating contracts with district-heating companies (light-shaded areas).

The figure includes production for three plants, i.e. Asnæsværket, Nordjyllandsværket and Fynsværket B7, which do not receive support under the *15-øren* (DKK 0.15) scheme. Neither Nordjyllandsværket nor Fynsværket B7 currently use woody biomass. However, Denmark's Energy and Climate Outlook 2019 (DECO19) assumes that they will use woody biomass from 2020.

Assuming plants will cease production after expiry of the *15-øren* (DKK 0.15) scheme, the demand for woody biomass will fall from around 14 TWh to 11 TWh in 2025 and will fall further to around 5 TWh in 2032. Note that, with this assumption, there will be a shortage of electricity and district heating and this shortage will have to be met by other means. DECO19 assumes the plants will stay in production after expiry of the *15-øren* (DKK 0.15) scheme, and that reinvestments will be made leading to production as illustrated in Figure 12 to Figure 14.

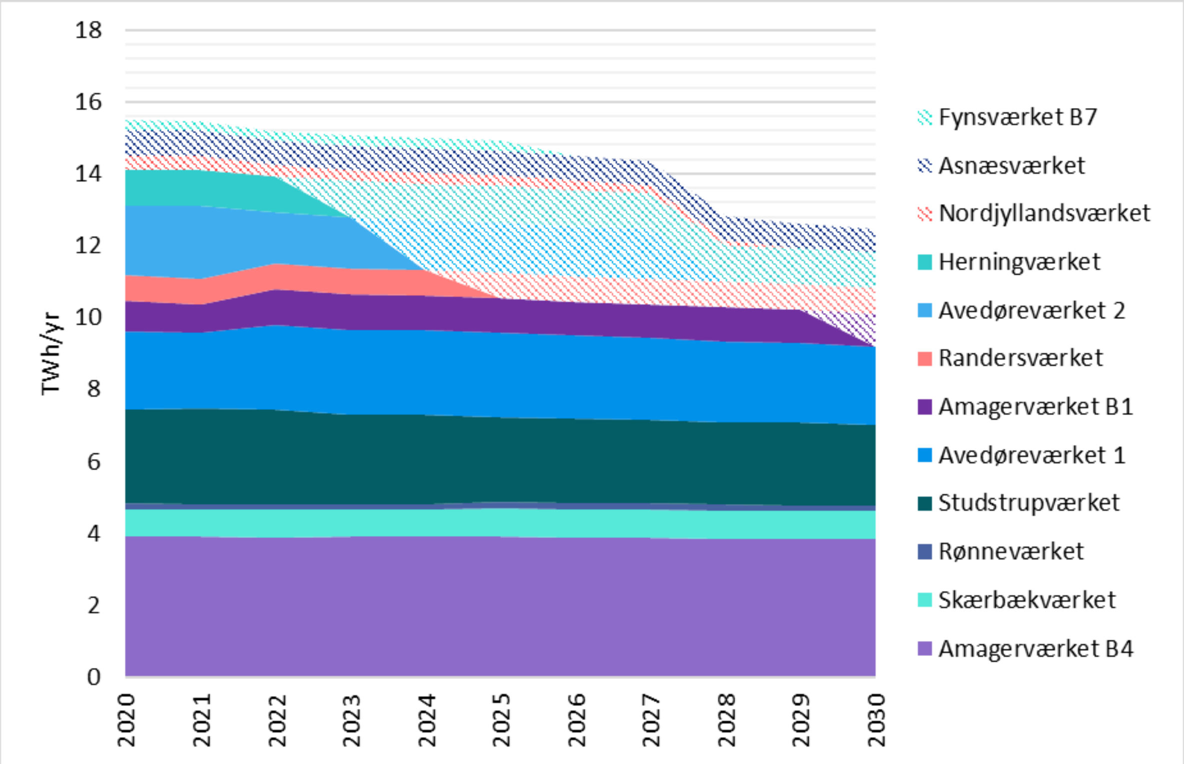


Figure 16 Wood consumption (in TWh) up to 2030 from large-scale CHP plants, assuming production will cease when the *15-øren* (DKK 0.15) scheme expires (dark-shaded areas) or when service-life extension is required (light-shaded area).

2. Reporting emissions from wood for energy according to international rules

This chapter describes the current international rules on reporting and calculating greenhouse gas emissions, including emissions from burning woody biomass. The rules are outlined in the United Nations Framework Convention on Climate Change (UNFCCC)[10] from 1992, the Kyoto Protocol from 1997[11] and the Paris Agreement from 2015[12]. Furthermore, the EU has common accounting rules pertaining to use of wood for bioenergy in the LULUCF sector.

The UNFCCC has no binding requirements for reducing emissions of greenhouse gases, but the Convention's methodologies for estimating greenhouse gas emissions are the basis for subsequent agreements. The Kyoto Protocol was the first internationally binding agreement on reducing emissions of greenhouse gases, as a number of developed countries agreed on reduction commitments. In 2015, the parties to the UNFCCC adopted the Paris Agreement, a new legally binding climate agreement with the long-term goal of keeping the global temperature increase well below 2°C and striving for a temperature increase of no more than 1.5°C.

The Paris Agreement commits the parties to submit national climate contributions, i.e. nationally determined contributions (NDCs), to the overall reduction of greenhouse gas emissions. The parties are free to choose how to word their mitigation targets, including what sectors to include. The EU has submitted collective climate contributions on behalf of Denmark and the other Member States: an overall greenhouse gas emission reduction of at least 40% in 2030 compared to 1990.

The collective climate contributions of all EU Member States are currently not sufficient to keep the global temperature rise below 2°C: let alone 1.5°C[13]. However, pursuant to the Paris Agreement, the parties must update their climate contributions to more ambitious contributions on a regular basis. The climate contributions are to be confirmed, updated or renewed every five years, starting in 2020.

Danish greenhouse gas emissions are estimated annually according to the UN guidelines. According to the UNFCCC reporting principle, emissions of greenhouse gases must be broken down by the following sectors: energy, industry, agriculture, land use and forests[14], waste, and other. The total greenhouse gas emissions of a country are the sum of its sectoral emissions.

Accounting for (assessing progress towards, and achievement of) mitigation targets under the Paris Agreement is based on existing UNFCCC guidelines[15]. The parties must account for their NDCs in a way that is transparent, accurate, complete, consistent and that safeguards against double-counting. However, apart from this, there are no common, agreed rules and methodologies for how to account for and calculate NDCs. Each country is therefore largely free to choose its own methodology,

[10] United Nations Framework Convention on Climate Change (UNFCCC).
[11] What is the Kyoto Protocol? https://Unfccc.int/kyoto_protocol
[12] The Paris Agreement, UN 2015.
[13] Synthesis Report on the Aggregate Effect of intended Nationally Determined Contributions (INDCs) https://unfccc.int/process/the-paris-agreement/nationally-determined-contributions/synthesis-report-on-the-aggregate-effect-of-intended-nationally-determined-contributions.

[14] Called *land use, land-use change and forestry* (LULUCF)
[15] Including the Kyoto Protocol and REDD+ (Reducing emissions from deforestation and forest degradation in developing countries).

definitions and calculation models, etc., which means there may be differences in how emissions and removals in the LULUCF sector are calculated and accounted for in NDCs across countries[16].

National greenhouse gas emissions are stated both with and without LULUCF-sector emissions. When referring to emissions figures, the figure without LULUCF is usually used.

CO_2 emissions from burning biomass are not included in energy-sector emissions and are therefore not included in total national emissions but are registered as a so-called 'memo item' for cross-checking purposes. The purpose of omitting emissions from biomass is to avoid double-counting. Biomass comes from the LULUCF sector, and emissions from biomass would be counted double if they were accounted for both under the LULUCF sector and under the energy sector.

Denmark reports emissions and removals from the LULUCF sector as part of regular reporting. LULUCF-sector emissions are included when assessing progress towards meeting the goal of a 70% reduction in greenhouse gas emissions by 2030 relative to 1990 set out under the Danish Climate Act. In years when more biomass is harvested for energy than trees and plants produce as they grow, Denmark will register emissions, potentially making it more difficult to achieve the 70% target. If less biomass is harvested than the growth in biomass, this will be registered as removals, potentially making it easier to achieve the target.

The UN reporting principle means that CO_2 emissions from burning imported biomass are not included in Denmark's national greenhouse gas emissions inventory. LULUCF-sector emissions from foreign biomass imported and burned in Denmark therefore do not affect Denmark's possibilities for meeting its 70% target. Instead, these emissions should be included in LULUCF-sector emissions in the national greenhouse gas inventory of the country in which the biomass was harvested.

Wood pellets from trees logged in Sweden are therefore accounted for as net removals in the Swedish LULUCF-sector accounts but count as zero emissions when they are burned at energy plants in Denmark. Similarly, emissions from use of Danish wood for energy are accounted for in the Danish LULUCF-sector accounts for forestry, irrespective of whether they are burned in Denmark or abroad. The LULUCF sector can contribute with net emissions if the carbon stocks in soils and forests decrease, e.g. due to deforestation, or can contribute with net removals if the carbon stocks in soils and forests increase, e.g. due to afforestation or if the forest growth exceeds forest harvesting.

Burning of imported biomass can lead to emissions globally if the harvested biomass reduces the total carbon stocks or sinks, or occasions emissions in other sectors in the country of origin. If the country of origin represents emissions from all sectors, including the LULUCF sector, truly and fairly and balances them against a binding and adequate mitigation target, such emissions can be offset by reductions in other sectors. Emissions from international maritime transport are calculated but are not included in national greenhouse gas emissions inventories.

The following describes the relevant, and closely related, guidelines for how to account for and calculate emissions from burning wood for energy purposes:

- The United Nations Framework Convention on Climate Change (IPCC)'s guidelines for calculating and reporting greenhouse gas emissions under the UNFCCC.
- The EU LULUCF Regulation establishes an accounting framework on top of the UNFCCC inventories to represent improvements or deteriorations in the carbon balance in soils and forests in progress towards meeting the EU mitigation target.

[16] Accounting for mitigation targets in Nationally Determined Contributions under the Paris Agreement, October 2017 Climate Change Expert Group, Paper No.2017(5).

- The EU burden-sharing agreement sets out more detailed rules on how to offset improvements (LULUCF credits) or account for deteriorations (LULUCF debits) in the carbon balance in soils and forests to show progress towards meeting the reduction commitments of Member States in the non-ETS sectors.

2.1 IPCC accounting guidelines

The UN's scientific intergovernmental climate change panel, IPCC, prepared and published guidelines in 1996 and 2006 for how to calculate emissions and removals of greenhouse gases. Parties to the United Nations Framework Convention on Climate Change, UNFCCC, are obligated to follow these guidelines when preparing their annual inventories and reporting to the UN and the EU. The reporting covers all sectors, including the LULUCF sector[17]. According to these guidelines, emissions from burning biomass may be reported as zero emissions in the energy sector, although this requires that the relevant emissions are included under the LULUCF sector instead.

The LULUCF sector comprises different types of land such as forest land, cropland, grassland, wetlands and settlements. The fundamental principle for estimating greenhouse gas emissions from forest land is that *net* removals or emissions of CO_2 are reported for a calendar year corresponding to the change that has taken place in the total carbon stock of forests from the start of the year to the end of the year.

In practice, most EU countries report the changes in the carbon pools of their forests by estimating the total carbon stock based on regular forest censuses. A fall in stocks from one inventory to another is reported as CO_2 emissions, while an increase in stocks is reported as removals. This means that changes in stocks correspond to the difference between forest growth and the loss of biomass, including, in particular, losses due to forest harvesting. The carbon stock in timber, wood panels and paper is estimated as a temporary stock that takes a long time to convert into CO_2[18]. These types of wood product are referred to as harvested wood products (HWP) in the context of reporting.

Harvesting for energy purposes is not measured and registered separately in the LULUCF estimates. The same applies to removals of carbon through normal tree growth. However, both are included in the total stock estimate.

Since the UNFCCC does not contain binding reduction requirements, there are no sanctions if LULUCF estimates reveal emissions or fewer removals than expected. The Kyoto Protocol, which was adopted in 1997, introduced legally binding reduction requirements for developed countries; however, not in the LULUCF area. The decision to place emissions from burning bioenergy in the LULUCF accounts therefore meant that bioenergy emissions and other LULUCF emissions were not included directly in the assessment of progress by developed countries towards meeting their reduction commitments.

2.2 EU LULUCF accounting rules

The EU has not included LULUCF in its accounting framework in the climate area for the period 2013 to 2020. However, with the adoption of the LULUCF Regulation[19], it was decided that LULUCF is to be included in the EU's target for greenhouse gas emission reductions under the Paris Agreement. At the same time, accounting rules were established for how Member States are to estimate national emissions and removals for the LULUCF sector.

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[17] In the most recent guidelines, from 2006, LULUCF and agriculture have been combined into the so-called AFOLU sector (agriculture, forestry and other land-use).

[18] The number of years it takes for the quantity of carbon stored in timber to decrease to one half of its initial value (i.e. the half-life) is assumed to be 35 years, for wood panels it is assumed to be 25 years, and for paper 2 years, according to Regulation (EU) 2018/841 of 30 May 2018.

[19]Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, etc. https://eur-lex.europa.eu/legal-content/DA/TXT/PDF/?uri=CELEX:32018R0841&from=EN

Thus, within the EU, a LULUCF accounting framework has been established which builds on top of greenhouse gas inventories for LULUCF under the UNFCCC. The objective of the accounting framework is to represent improvements or deteriorations in the carbon balance in soils and forests in progress towards meeting mitigation targets. More specifically, this accounting framework gives 'LULUCF credits' for improvements in the carbon balance in soils and forests, and 'LULUCF debits' for deteriorations, including in situations in which large consumption of bioenergy leads to depletion of the carbon pools of forests. Up to a certain emissions cap, credits can be used to offset emissions in other sectors, while debits are to be added to emissions from other sectors.

From 2021, LULUCF credits can be used to offset Member States' emissions in the non-ETS sector. These emissions are regulated by the EU burden-sharing agreement which covers emissions from transport, buildings and agriculture, for example. There is a total EU cap of 280 million tonnes of CO_2 for offsetting LULUCF credits in the non-ETS sector in the period 2021 to 2030. This cap has been distributed among Member States on the basis of the share of agricultural emissions in total non-ETS-sector emissions 2008 to 2012. Denmark can offset 14.6 million tonnes of LULUCF credits in the commitment period running from 2021 to 2030. Deteriorations in the carbon balance of Member States lead to debits, which must be added, in full, to the individual Member State's non-ETS-sector emissions. Finally, the LULUCF Regulation includes a 'no net debit' requirement for emissions from the LULUCF area in the periods 2021 to 2025 and 2026 to 2030. The Regulation also includes a compensation mechanism, which allows a number of 'forest countries' to increase harvesting corresponding to a total of 360 million tonnes CO_2 in the period 2021 to 2030. The compensation is a technical transfer of an expected net removal from other LULUCF sectors, in particular, such as agricultural land and afforestation, which, due to the 280-million-tonne cap, are expected to be in surplus (net credits).

There are separate LULUCF accounting rules for agricultural land, afforestation, deforestation and forests older than 20 or 30 years[20]. The accounting rules for older forests are as follows: Improvements/deteriorations in the carbon balance are calculated relative to a dynamic age-related forest reference level[21]. The forest reference level is an expression of the expected net emissions or net removals from the forest if the country's forest management practice in the period 2000 to 2009 is continued. The management practice for the reference-period is assumed to be applied with the forest-age structure which, on the basis of model projections from the status in 2010, it is assumed the forest will have in 2021 to 2025 and 2026 to 2030, respectively. For example, if 5% of trees aged between 80 and 90 were felled annually in the period 2000 to 2009, then the same harvesting intensity should be assumed for trees of the same age class in the period 2021 to 2030. If the number of old trees aged between 80 and 90 has doubled in the period 2021 to 2030, harvesting is assumed to still be 5%, corresponding to a doubling of the total volume relative to the period 2000 to 2009.

If there are net removals/fewer emissions than the forest reference level, this will lead to LULUCF credits. On the other hand, increases in harvesting intensity in the forest relative to the harvesting intensity in the period 2000 to 2009 can lead to debits. The 2000-2009 reference period lies largely before the adoption of the EU Renewable Energy Directive in 2008, which led to an increase in the use of biomass for energy.

Many EU Member States lack data about their forests and management practice from the reference period, and estimates are generally associated with very large uncertainty. In addition to this, Member States use different methodologies for collecting and processing data. The LULUCF Regulation contains only rather general criteria for how to calculate individual forest reference levels. Forest reference levels can be decisive for whether a Member State receives LULUCF debits or LULUCF credits. Member States propose their own forest reference levels, which then have to be approved

[20] The EU rules apply an afforestation period of 20 years. Member States can choose a 30-year period if they provide an appropriate reason based on the IPCC guidelines. Denmark, amongst others, has chosen to do so, see the Danish National Forest Accounting Plan 2021-2030.

[21] The forest reference level (FRL) is to ensure that carbon stocks are not included in accounts by virtue of their mere existence, see the LULUCF Regulation. The reference level includes the carbon pools from harvested wood products.

through a review process with the participation of experts from the Member States and from the European Commission.

2.3 Denmark's mitigation target and LULUCF estimate

From 1990, the UN base year for assessing progress in climate change mitigation efforts, up to 2017, Denmark's reported greenhouse gas emissions have been reduced by 29%. The trend in total emissions over the period, excluding the LULUCF sector, are shown in Figure 17. In the figure, CO_2 emissions from burning biomass have been set at zero in accordance with international rules.

The figure shows that the most significant reduction so far has been in the electricity and district heating sector, where observed emissions fell by almost 21 million tonnes from 1990 to 2017, corresponding to a reduction of 63%. The large drop is due to increased use of biomass, wind and other renewable energy by the sector, as described in chapter 1.

In 2018, woody biomass was responsible for 42% of emissions, other bioenergy for 24%, and wind, solar, etc. for 34% of the sector's energy consumption. The increased use of woody biomass for electricity and district heating production is therefore responsible for a significant share of the recorded emissions reduction in Denmark up to the present.

Emissions from the electricity and heating sector are expected to continue to drop up to 2030, when emissions are expected to have dropped by 92% compared with 1990.

2.3.1 Biomass burning

As mentioned above, countries that are parties to the UNFCCC are to report their emissions from all biomass burning as a 'memo item'. This memo item includes both nationally produced biomass and imported biomass. For Denmark, this memo item shows an increase in emissions from burning solid biomass, including biogenic waste and liquid biofuels, from 4.4 million tonnes CO_2e in 1990 to 18.8 million tonnes CO_2e in 2017. Without liquid biofuels and biogenic waste, emissions were 15.6 million tonnes CO_2e in 2017[22]. Emissions from international aviation and international maritime transport are reported as other memo items and therefore do not count towards national emissions.

22 Denmark's National Inventory Report 2019. Emission Inventories 1990-2017 – Submitted under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol.

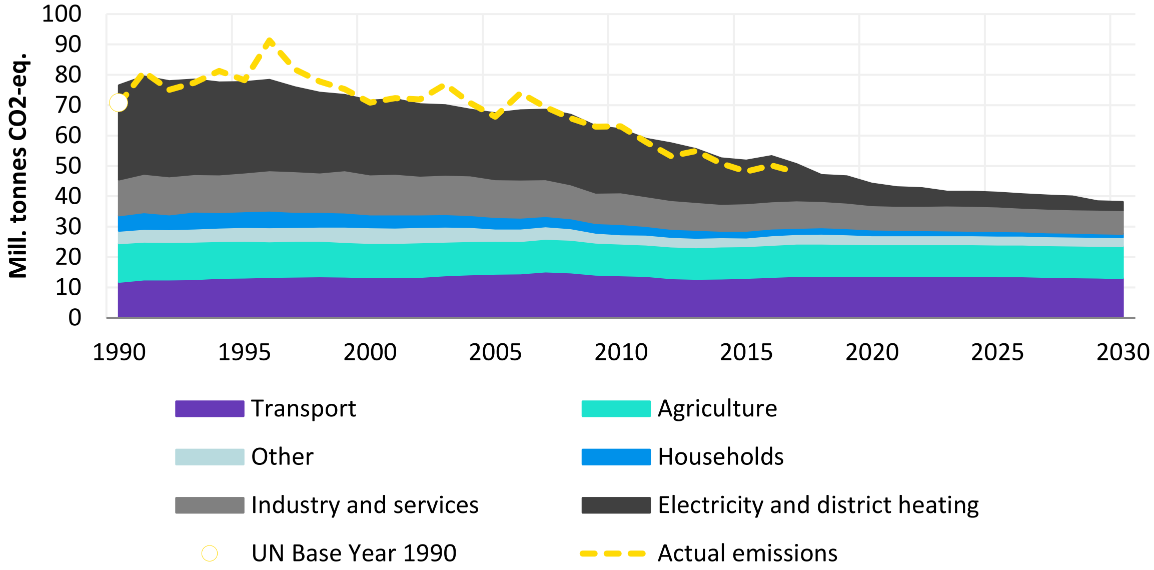

Figure 17. Emissions of greenhouse gases by sector 1990-2030 in the absence of new political initiatives and in the 1990 UN base year [mill. tonnes CO_2-e]. The statistics for 1990-2017 have been adjusted for foreign trade in electricity. Reduction targets are based on observed emissions relative to the UN base year and excluding LULUCF. LULUCF emissions are estimated separately. Source: Danish Energy Agency, Denmark's Energy and Climate Outlook 2019 (DECO19).

2.3.2 The Danish LULUCF sector

The Danish LULUCF sector is generally responsible for 0-8% of total Danish emissions[23]. Emissions and removals from the sector vary greatly from year to year, as is evident from Table 2.

Unit: Mill. tonnes CO_2 equivalents (CO_2e)	1990	2000	2005	2010	2015	2017	2018
Observed emissions	76.9	76.2	72.3	63.7	53.4	52.5	54.5
Of which LULUCF	6.5	5.2	6.0	0.6	5.2	4.4	6.5

Table 2 Total emissions of greenhouse gases, including LULUCF. Source: Danish Energy Agency energy statistics for 2019, preliminary figures.

In general, Danish forests have been net sinks, while Danish soils have been net sources, e.g. due to emissions from drained organic soils. Danish forests were large sinks until 2014, after which time they had net emissions in 2015 and 2016 and then net removals in 2017. The net removals from forests were 0.5 million tonnes CO_2e in 1990 and 0.1 million tonnes CO2e in 2017, and, as an average over the period, 1.2 million tonnes CO_2e/year.

The LULUCF estimate for Danish forests includes the carbon stock in living biomass and in dead wood, the carbon content in forest soils and emissions of methane and nitrous oxide. There is considerable uncertainty in these figures. Amongst other things, this is because they represent small variations in very large stocks, the size of which have been estimated using different methodologies over the period.

2.4 Status for mitigation targets and LULUCF estimates for imported biomass

The mitigation targets set by countries throughout the world differ considerably and are subject to different rules and guidelines depending on whether the country is an EU Member State, a party to the

[23] Total emissions including LULUCF, average for 2013-2017.

UNFCCC, the Kyoto Protocol and/or the Paris Agreement, and whether the country is a developed or an developing country.

Some countries have mitigation targets under the Paris Agreement, others do not. A total of 186 countries have submitted mitigation targets (NDCs) to the UN. Some countries, such as Russia, currently have no mitigation target. The US has announced its secession from the Paris Agreement as of November 2020. Some countries have submitted mitigation targets which can be reached without any additional action. The mitigation targets submitted so far are not sufficient to limit the global temperature rise to 2°C[24]. Furthermore, even if a country has submitted an NDC, there is no guarantee the country will meet the target.

According to the LULUCF Regulation, EU Member States are to include LULUCF in their mitigation targets from 2021. For countries outside the EU, there is some variation as to whether LULUCF is included in their target or not. So far, in practice, LULUCF has not been widely included in the mitigation targets of countries, according to the Danish Council on Climate Change[29].

Not all countries report their LULUCF emissions and removals. The developed countries have long been required under the UNFCCC and the Kyoto Protocol to report their LULUCF emissions and removals to the UN on an annual basis. The Paris Agreement encourages, but does not require, the parties to include LULUCF in their greenhouse gas inventories.

Developing countries have just recently started reporting biennially. Most developing countries have yet to submit their first report, and not all reports submitted by developing countries include emissions and removals from the LULUCF sector. In March 2020, 54 of 142 countries had submitted their Biennial Update Report (BUR) with emission inventories[25].

Countries that calculate and report LULUCF emissions and removals use different calculation methods. The many options for how to estimate emissions make it difficult to compare the results and levels of ambition of countries, unless the LULUCF sector is excluded[26]. According to the Danish Council on Climate Change, when the LULUCF sector is included in mitigation targets, greenhouse gas inventories and mitigation targets become less transparent and it becomes more difficult to keep track of whether countries are actually meeting their emission commitments[27, 28].

It is not possible on the basis of reported LULUCF estimates to determine whether biomass imported from other countries and burned in Denmark has contributed to reducing forest carbon stocks or sinks. If biomass imported from countries without binding and adequate mitigation targets, or without truly and fairly represented LULUCF estimates, has reduced carbon stocks or sinks, there will not, in practice, be evidence for setting emissions from biomass burning at zero.

The US and Russia are examples of countries from which Denmark imports biomass and which either have no mitigation target that includes the LULUCF sector, or whose LULUCF estimates are subject to doubt about whether they represent and include emissions and removals truly and fairly against a binding target. In 2018, Russia and the US together supplied around one quarter of the biomass imported by Denmark for energy purposes.

[24] Synthesis Report on the Aggregate effect on intended Nationally Determined Contributions (iNDCs), UNFCCC 2016.
[25] https://unfccc.int/BURs
[26] https://climateactiontracker.org/methodology/indc-ratings-and-lulucf/.
[27] Accounting for Mitigation Targets in Nationally Determined Contributions under the Paris Agreement, OECD, October 2017.
[28] The Role of Biomass in the Green Transition, Danish Council on Climate Change 2018.

3. Climate impact and sustainability of woody biomass for energy

Chapter 2 outlined how a country's total national greenhouse gas emissions should be calculated as the sum of emissions from various sectors: energy, transport, industry, soils and forests, etc.

This sectoral approach does not provide a picture of the overall climate impact of using biomass for energy, because there could be increased or reduced emissions in several different sectors: In the energy sector, biomass may replace fossil energy. In the transport sector, lorries, ships and trains that transport biomass use fossil energy[29]. In the industry sector, wood pellet factories may use fossil energy for drying and pressing. In the soils and forests (LULUCF) sector, the removal (harvesting) of biomass for energy affects emissions and removals. Sectoral emissions inventories can therefore include the climate impacts of using biomass, but these impacts are included as an unidentifiable subset.

For the above reason, the climate impact of using biomass for energy is therefore also estimated by other methodologies: life cycle assessments (LCAs). Life cycle assessments assess climate impacts (and any environmental impacts and resource consumption) linked to a specific product or service, in our case the use of biomass for energy[30]. Life cycle assessments include the complete life cycle of biomass across sectors. Life cycle assessments are often used to compare different options. For example, what is the climate impact of replacing coal with wood pellets in a specific power plant for the next ten years? Or what is the global climate impact of a new common EU policy to promote the use of biomass up to 2050? Life cycle assessments like these compare one or several scenarios with one or more alternatives, typically including a 'business as usual' scenario.

Many different life cycle assessments have been prepared on the use of biomass for energy. They have addressed various questions, looked at different types of biomass, defined different system boundaries, used different assumptions, looked at different alternatives and time periods, and have arrived at different results.

The IPCC has summarised life cycle assessments for different energy technologies[31] and has concluded that CO_2 emissions from biomass from forests fall within a very broad size range but that they are generally several times greater than similar life cycle emissions from wind and solar. Among other things, this is because, in the case of biomass, production of the fuel is linked to continuous emissions, whereas wind and solar are fuel-free sources of energy.

A life cycle assessment of the climate impacts of biomass consumption prepared by Robert Matthews et. al.[32] contains a number of scenarios for the EU's future use of biomass for energy. This analysis reveals that the scenario limiting the consumption of biomass the most provides the greatest CO_2 reduction but also necessitates a larger consumption of other renewable energy sources. Furthermore, the analysis reveals that the next best route to reducing CO_2 is through EU prioritisation

[29] According to international guidelines, emissions from international maritime transport should not be included in national inventories.
[30] According to Commission staff working document, Impact Assessment, Sustainability of Bioenergy (SWD/2016/0418 final, 30.11.2016), climate impacts of using biomass for energy are best assessed through an impact assessment analysis (LCA) that includes all carbon stocks, also biogenic emissions.
[31] https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter7.pdf
https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf#page=7
[32] "Carbon impacts of biomass consumed in the EU", Robert Matthews et. al. 2018

of biomass, whereas scenarios that allow the greatest quantities of biomass in the energy system, including imported woody biomass from non-EU countries, provide the lowest CO_2 reductions

The European Commission has assessed the climate sustainability of bioenergy on the basis of Robert Matthew's study and a number of other large studies[33,34,35]. The Commission concludes that the climate impact of using biomass for energy varies and that the use of forest biomass, in particular, for a period can lead to insignificant reductions or even to increased CO_2 emissions compared with fossil energy.

In the Commission's assessment, there is a risk that increased use of biomass could lead to additional harvesting of trees for energy, which would have a negative climate impact[36]. The risk is greater when the biomass is imported from countries outside the EU. The Commission has also assessed other sustainability aspects and has concluded that production and use of biomass for energy can have negative impacts on biodiversity and on the quality of soil and air. Below is a more detailed outline of the Commission's conclusions:

- Biomass from forests cannot generally be assumed to be CO_2 neutral.
- The climate impact of burning forest biomass varies.
- Forest management affects carbon stocks and carbon removals (sinks).

Biomass from forests cannot generally be assumed to be CO_2 neutral
Burning woody biomass releases CO_2, just as burning coal or other fossil fuels does. The CO_2 released was originally absorbed by the trees as they grew, and when the trees have been felled, any growth of new trees will then re-absorb CO_2 from the atmosphere. This principle has led to the assumption that biomass 'in itself' is CO_2 neutral, because the emissions are offset by corresponding removals. Based on this assumption, many analyses have set the CO_2 emissions from biomass burning itself at zero.

The Commission, however, concludes that this assumption is generally not applicable to forest biomass. The reason for this is twofold: 1) Biomass burning is not always offset by removals and even if is offset by removals, a time lag between burning (emissions) and removals will have climate impacts. 2) In most situations, biomass when burned emits more CO_2 via the chimney than the fossil alternative that it replaces. This is due to the lower energy content per kg carbon in biomass compared to coal, for example, and in most situations, also a lower efficiency in the conversion to electricity, for example. The Commission therefore concludes that life cycle analyses should include global emissions from all relevant carbon stocks if they are to give a true and fair view.

The time lag between the release of the CO_2 and its re-absorption (removal) can contribute to a 'carbon debt'. When wood is burned, CO_2 is released immediately, while the offsetting CO_2 removals take place over a several years. The time factor is significant because the concentration of CO_2 in the atmosphere determines the rate at which climate change takes place. Use of biomass can therefore have an impact on the climate even if new trees are planted (forest regeneration) and/or despite subsequent tree growth.

A single tree can take many years to absorb the CO_2 that was released from the process of burning of a similar tree. An entire forest can absorb and store a lot of carbon each year, and if no more wood is removed from the forest than is regenerated each year, and if the carbon stocks in the forest floor and soils remain unchanged, then the forest can strike a 'carbon balance'. For example, in the period from

[33] JRC, 2014: 'Carbon Accounting of forest bioenergy' and Forest Research, 2014: 'Review of literature on biogenic carbon and life cycle assessment of forest bioenergy'.
[34] Carbon Impacts of biomass consumed in the EU. Robert Matthews et. al. 2018.
[35] Commission staff working document, Impact Assessment, Sustainability of Bioenergy (SWD/2016/0418 final, 30.11.2016).
[36] i.e. leads to increased emissions.

2014 to 2018, only 74% of Danish forest growth was removed[37]. If removals of woody biomass from forests exceed forest growth or are increased, this could once more lead to a carbon debt.

There is disagreement about whether biomass can be called CO_2 neutral if there is a balance between biomass removal and CO_2 sequestration in a given forest[38]. This is because around one-fifth of anthropogenic CO_2 emissions to the atmosphere are absorbed by trees and other plants. The rising content of CO_2 in the atmosphere moreover has a fertilising effect, leading to increased growth in the world's forests. If the *entire* annual growth in forests is burned, then the carbon which the trees have stored will be released to the atmosphere again. Thus, an important feedback mechanism is affected which is of significance for global warming.

The climate impact of burning forest biomass varies

The Commission concludes[43] that the overall climate impact of using biomass for energy varies and that the use of forest biomass, in particular, can lead to insignificant reductions or even to increased CO_2 emissions compared with fossil energy. The impact varies depending on a number of factors, including the magnitude of consumption. The higher the consumption of biomass for energy, the greater the risk that this use of biomass will lead to a high level of emissions. Other important factors include: the type of biomass used, forest management practices, market effects, time perspective, the alternative use of land and biomass, and the alternative energy source.

Forest residues, thinnings, industrial wood residues and waste wood are generally associated with a low level of emissions. Therefore, when these residues replace coal, there will be a rapid reduction in CO_2 emissions.

For large tree trunks[39], tree stumps and roots, emissions are higher - and may for a period even be higher than for the fossil alternative. The length of the period when emissions are higher than for the fossil alternative may vary from less than one year to several hundred years or, in a worst-case scenario - indefinitely[40].

Forest management affects carbon stocks and carbon removals

Increased biomass harvesting (removals) from forest land will typically reduce the forest carbon stock but may also increase the stock in certain situations, i.e. in connection with afforestation that does not entail land use change impacts (ILUCs), and through a number of specific management methods involving higher planting density or longer rotation. Even in the case of sustainable forestry, where biomass removals do not exceed forest growth, the carbon stock will typically still be lower than in non-managed forests[41].

Efficient plantations with fast growing tree species may in some cases both have a high level of CO_2 uptake and contain a high carbon stock in the form of living biomass (growing stock). Older forests grow and absorb CO_2 at a slower rate than medium-age and younger forests, but at a faster rate than entirely newly planted forests. Regeneration of older forest stands may therefore lead to increased emissions/less uptake in the short term but increased uptake in the long term[42]. In old natural forests, the net growth has subsided, and the forest is approaching a carbon balance between forest growth and the release of CO_2 from dead wood[43].

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[37] Skovstatistik 2018 (forest statistics) 2018, Thomas Nord-Larsen et. al. University of Copenhagen 2019.
[38] Klimapåvirkning fra biomasse og andre energikilder (climate impact of biomass and other sources of energy), Concito, 2013.
[39] Sawn wood & coarse dead wood.
[40] Commission staff working document, Impact Assessment, Sustainability of Bioenergy (SWD/2016/0418 final, 30.11.2016).
[41] Carbon accounting of forest bioenergy, JRC European Commission, 2014.
[42] Klimaskoven - et effektivt redskab til håndtering af CO_2 –problemet (The climate forest - an effective approach to tackling the CO_2 problem), Esben Møller Madsen, Anders Tærø Nielsen, Palle Madsen and Per Hilbert. Træ.dk.
[43] Klimaeffekter af urørt skov og anden biodiversitetsskov (Climate impacts of virgin forests and other biodiversity forests), Vivian Kvist Johansen et. al., University of Copenhagen 2019.

3.1 The climate impact of Danish use of biomass

Determining the real climate impact of burning biomass requires an accurate definition of the biomass production system, the energy system and the time period applied, compared with relevant alternatives. There is currently no accessible data basis for calculating the real, overall climate impact of using biomass for electricity and heating in Denmark.

However, due to a sector agreement between the Danish Energy Association and the Danish District Heating Association to ensure the use of sustainable biomass, information is available on emissions in the production chain, e.g. emissions from transport, drying and processing biomass. The emissions have been estimated as greenhouse gas savings compared with a fossil reference. The CO_2 reductions reported in 2017 by the energy plants covered by the sector agreement corresponded to 75-95% of the fossil emissions reference. Thus, for these plants, emissions from the production chain constitute 5-25% of emissions from fossil energy. There is no data available on emissions in the production chain for biomass consumption not covered by the sector agreement.

The new EU Renewable Energy Directive defines a methodology for estimating production chain emissions from the use of biomass fuels. Total emissions from the use of biomass should be calculated as the sum of net emissions of greenhouse gases from cultivation, changes in carbon stocks due to land use changes, processing, transport and burning of biomass. The Directive still sets CO_2 emissions from burning biomass to zero following the international rules on how to calculate emissions from biomass. The purpose of estimating emissions in the production chain is to determine whether the biomass meets sustainability requirements, see chapter 5, and they are not included in national greenhouse gas inventories.

The Renewable Energy Directive contains a number of default values for emissions from the cultivation, processing and transport of different types of biomass. For woody biomass, emissions from cultivation are often insignificant, while emissions from transporting wood chips and from processing wood pellets, in particular, may be significant in certain situations.

3.2 Residues

The use of residues from merchantable wood production instead of fossil energy sources leads to rapid CO_2 reductions, and the impact on the climate will therefore quickly be positive. This is because 'residues', e.g. sawdust or dead wood, would otherwise quickly decay and thus release CO_2. For thick branches and trunks removed for energy purposes rather than being left in the forest, it will take longer before the climate impact is positive. Amongst other things, the time frame depends on the decay factor: i.e. the time it takes for the material to decay and release the CO_2 stored within it.

The term 'residue', here, indicates that the material came about as part of a production process that is not for energy purposes, i.e. timber or furniture production. Where this is the case, the tree would have been felled regardless. Residues are therefore not assumed to have indirect land use change impacts.

To be defined as residues, there must be no 'higher option' for use of the product, see the EU waste hierarchy. For woody biomass, 'higher options' include using the biomass to produce furniture, timber, paper, plywood and chipboard, which are often more valuable uses than converting the biomass to electricity and heat in a CHP plant.

Wood for timber can usually be sold at a higher price than wood for energy, and so it is typically assumed that wood that can be sold for timber is in fact sold for timber. Wood for paper and chipboard is less valuable and, here, local market conditions and transport distances may influence the purpose for which the biomass is sold[44].

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[44] Memorandum on woody biomass prepared by the Danish Energy Agency in connection with implementation of the Renewable Energy Directive, NEPCon 2020.

If wood residues are in high demand, this could lead to production changes to ensure that more residues are generated. For example, in merchantable wood production, one might choose to plant more trees per hectare with a view to thinning. Or a change might be to increase felling rates in an area that was not cultivated for wood production and where most of the trees are therefore not suited for timber.

Thus, the distinction between 'residues' and 'product' is blurry, it changes over time and is determined by technological factors and market conditions.

3.3 Other sustainability aspects

Climate is not the only sustainability aspect associated with the use of biomass for energy. Other aspects include social sustainability, biodiversity and resource concerns. Social sustainability is about the consequences of products for local communities and indigenous peoples, and about conditions of labour, etc. These conditions will not be addressed in more detail in this report. The following will address land use and biodiversity, while the question of the amount and availability of resources are dealt with in chapter 4.

3.3.1 Biomass and land area

Bioenergy can be a space-consuming type of energy[45]. Wind and solar energy are among the least space-consuming renewable technologies, while bioenergy belongs to the more space-consuming types of energy.

For example, the energy output from solar PV is assessed to be 15-100 times greater per unit of area than bioenergy[46,47,48], depending on the calculation method and assumptions. However, it should be remembered that we are talking about different types of energy: bioenergy can be stored and can be used in different ways. This contrasts with electricity from solar and wind energy.

Incorporating more land for energy production entails a risk of direct and indirect land use change impacts (LUCs and ILUCs). For example, when planting forest on agricultural land, there is a risk that the production of food products will merely be moved to other land, where it might replace forest, perhaps even tropical forest with a large carbon stock and high biodiversity. Depending on the type of land in question, there could be climate impacts of such changes in land use. If rainforest is cleared, the negative climate impacts will be considerable. Increased production of wood in Denmark, on the other hand, could reduce harvesting for wood in forests outside Denmark, thus giving rise to positive climate impacts.

3.3.2 Biodiversity

Increased consumption of biomass for energy can increase the pressure on biodiversity. This is partly because the production of biomass for energy takes up land, which can lead to direct and indirect land use change impacts that affect biodiversity. It is also because the sales potential of biomass could lead to a reduction in the dead wood volumes in forests as residues are removed from the forest. Finally, intensively managed forests with fast-growing non-native species have lower levels of biodiversity than natural forests, for example.

In the most recent report on the status of nature in Denmark, which was prepared for the European Commission pursuant to the Habitats Directive, the conservation status for all ten forest habitat types in the Directive's list is assessed to be 'unfavourable-bad'. Negative factors include intensive forest

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[45] Danish Society for Nature Conservation https://issuu.com/danmarksnaturfredningsforening/docs/energiforsyningspolitik_2018_lav_op

[46] Energy, Water, and Land Use. In: Climate Change Impacts in the United States: The Third National Climate Assessment, Chapter: Energy, Water, and Land Use, Publisher: US Global Change Research Program, Editors: JM Melillo, TC Richmond, GW Yohe.

[47] "Energy and land use". Global Land Outlook working paper September 2017 by Uwe Fritsche, Göran Berndes et. al.

[48] Avoiding bioenergy competition for food crops and land, T. Searchinger et. al., World Resource Institute.

management with harvesting, felling of large trees, thinning of stands, removal of dead wood and dying trunks, converting of forest, chipping of wood and draining[49].

Valuable land may have to be mapped to protect it. Denmark has surveyed particularly valuable land in publicly owned forests50. A similar survey of privately owned forests was planned as part of the 2016 Nature Package but has yet to be carried out. Privately owned forests make up around 70% of all forest land in Denmark and, for historical reasons, contain most of the habitats of endangered species.

A risk assessment for Denmark has been carried out in the context of the Sustainable Biomass Program (SBP)[51] certification scheme[52]. This assessment concluded that forest biodiversity in Denmark has not been sufficiently mapped and is not sufficiently protected to merit the status of 'low risk' with regard to biodiversity. On four indicators related to forest biodiversity, the assessment report gave a rating of 'specified risk'.

3.4 Conclusion about the climate impact of biomass

On the basis of chapters 2 and 3, it can therefore be concluded that although international guidelines allow for the consumption of biomass by the energy sector to be counted as zero emissions in Denmark, there is a risk that Danish biomass consumption by the energy sector could cause emissions globally.

In the case of forest biomass, consumption in Denmark may cause considerable emissions due to reduced carbon stocks or reduced CO_2 sequestration in forests. Furthermore, there may be emissions from the biomass production chain in the range of 5-25% of the emissions from fossil energy, which is significantly more than the corresponding emissions from wind and solar.

The use of biomass for energy in many cases benefits the climate, e.g. when residues-based biomass replaces fossil fuels. Other situations, e.g. cutting down trees for energy production without replanting new trees, contributes more to climate change than if coal had been used instead.

A detailed calculation of the climate impact of biomass requires accurate definition of the system analysed and the biomass used, the relevant time period and the alternatives. There is currently no accessible data basis for calculating the real, overall climate impact of using biomass for electricity and heating in Denmark.

According to international rules, emissions from burning biomass should be accounted for under the LULUCF sector, and in other sectors in the respective countries of origin and not under the energy sector in the country where the biomass is burned. In order to be true and fair, this accounting principle requires that all countries supplying biomass to Denmark have binding and adequate mitigation targets and include all sectors correctly, including the LULUCF sector. If these requirements are met, any emissions in the LULUCF sector will be compensated for by an increased reduction effort in other sectors. However, this is currently not the case.

[49] Bevaringsstatus for naturtyper og arter. Oversigt over Danmarks Artikel 17-rapportering til habitatdirektivet 2019 (Conservation status for natural habitat types and species. Denmark's Article 17 reporting under the Habitats Directive). Memorandum prepared by the Danish Centre for Environment and Energy (DCE). Date: 6 September 2019.

[50] Status for kortlægning af økosystemer, økosystemtjenester og deres værdier i Danmark (Status on mapping of ecosystems, ecosystem services and their values in Denmark). Danish Centre for Environment and Energy (DCE) 147 2015. In 2016-2017, the Danish Environmental Protection Agency surveyed and recorded forest land of high nature value in areas owned by the Danish state, regions and municipalities. Forests with high nature value, in a Danish context known as section-25 forests, contain extraordinary and above-average nature values. This type of forest is hugely significant for the conservation of biodiversity in Denmark. The mapping of forest land of high nature value is based on section 25 of the Danish Forest Act.

[51] Sustainable Biomass Partnership.

[52] SBP-endorsed Regional Risk Assessment for Denmark, 2017.

4. Global and national biomass resources

This chapter describes the size of global biomass resources, including global consumption of biomass, trends in carbon stocks and assessments of the global sustainable potential of biomass for energy. Finally, the chapter outlines the national biomass resources for energy.

4.1 Global demand for biomass for energy

According to the International Energy Agency (IEA), global consumption of biomass for energy was 37.3 EJ in 2017. Solid biomass here includes wood charcoal, firewood, wood pellets, wood chips, bagasse, dried livestock manure for fuel, straw, residues from agriculture, and industrial waste. Consumption by use is shown in Table 3.

2017	Exajoule (EJ)
Households	27.8
Industry	8.0
Trade & service	1.0
Agriculture and forestry	0.4
Other	0.1
Total	37.3

Table 3 Global consumption of biomass in 2017. Source: IEA.

A major share of biomass consumption in households is 'traditional' biomass, i.e. consumption of fuel in the form of firewood and dried livestock manure for cooking, etc. in developing countries.

So-called 'modern' bioenergy, i.e. biomass used at electricity and heating plants, in industry, etc. accounted for around half of the global consumption of renewable energy in 2017. Renewable energy made up 10.4% of total energy consumption in 2017. The IEA expects bioenergy to be the renewable energy type to increase the most in the period 2018 to 2023[53].

4.2 Global forest carbon stocks

The global forest area is still in decline[54], but this overall trend represents a number of underlying opposing trends: decline in natural forests, growth in plantations, decline in Latin America, Africa and Indonesia, progress in China, Europe and the US. The forest carbon stock is generally increasing in the northern hemisphere. An outline of the global development in forest carbon stocks from 1990 to 2015 is shown in Figure 18.

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[53] IEA Market Report Series. Renewables 2018.

[54] The State of the World's Forests, Food and Agriculture Organization of the United Nations (FAO) 2018.

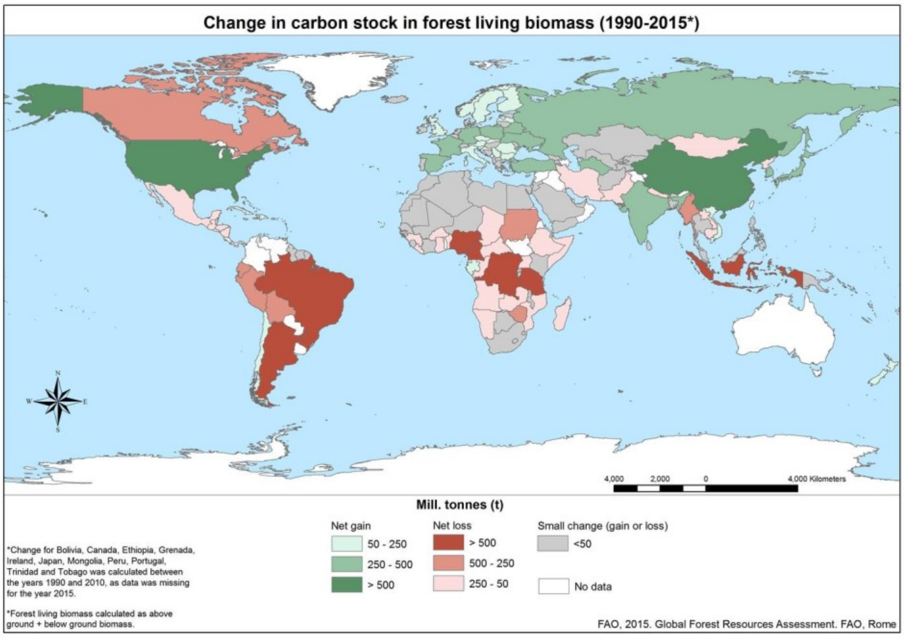

Figure 18 Changes in forest carbon stocks globally, 1990 – 2015. Source: FAO

4.3 Global sustainable biomass resources

According to the IPCC, people cultivate or impact more than 70% of the world's total ice-free land area, and annually make demands on 25-33% of land-based net primary production (NPP), i.e. the energy which is stored annually by plants through photosynthesis[55]. The need for land and biomass for food, fodder and materials will likely increase in step with the anticipated increase in the world's population from 7.6 billion today to 9.7 billion in 2050.

There have been several and very different assessments of the global bioenergy potential. The assessments range from less than 100 to more than 300 EJ:

- Up to 100 EJ: Assessments that arrive at a total potential of up to 100 EJ from waste/residues, energy crops and forests assume there is only a limited area available for energy crops, that livestock farming will continue, that the area of farmland will not increase significantly, and that there will be no significant increase in productivity in agriculture.

- 100 – 300 EJ: Assessments that arrive at a total potential of 100-300 EJ assume a relatively high potential from waste products and residues, that productivity in agriculture will increase in step with population growth, that the forest area will be reduced by 25% or will be replaced by fast-growing energy forests, and that a significant area (of 2-10 times the area of France) that was previously natural grassland or forest will be designated for the production of energy crops.

- Over 300 EJ: Assessments over 300 EJ assume that productivity in agriculture will increase significantly faster than population growth and that an area the size of China will be used for energy crops.

The IPCC has assessed that by 2050 the global sustainable bioenergy potential will be limited to around 100 EJ per year, and only some of this potential will come from wood. According to the IPCC,

[55] IPCC: Climate Change and Land 2019.

consumption at or above this level will put considerable pressure on available land, food production and prices[56].

A maximum potential of 100-300 EJ biomass corresponds to 10-30 GJ per person per year in 2050. Danes today consume around 27 GJ biomass per person for energy, of which around 20 GJ is woody biomass[57].

4.3.1 Residues from forests

Bentsen and Stupak (2014)[58] have estimated the global potential for residues from logging for the period 2010 to 2020, based on assessments of logging residues from commercial forestry. The estimate is presented in Table 4.

Region	Wood resource potential 2010-2020
Northern Europe	242-891
Baltic countries	58-159
Western Europe	250-1403
Eastern Europe (excl. Russia)	142-790
Southern Europe	267-618
Russia (north-western part)	223-749
North America	1845-2300
South America (in 2050)	1400

Table 4 Woody biomass potentials from different regions in PJ. Source: Bentsen, 2015.

For Europe, excluding Russia, the potential is estimated at 0.96-3.86 EJ. Bentsen and Stupak place the sustainable potential in the lower end of this range, while the upper end is referred to as a technical potential. If Russia and North America are included, the total potential is estimated at 3.03-6.91 EJ.

In 2016, the total consumption of biomass in the EU was 5.86 EJ, of which 4% was imported from third countries[59]. Consumption of woody biomass from the EU amounted to 3.43 EJ in 2016. Consumption of solid biomass in the EU more or less doubled from 2000 to 2017 and is still growing, although at a slower pace than wind power and heat pumps. Bioenergy accounts for around 60% of renewable energy consumption in the EU.

The EU's long-term climate strategy[60] anticipates an increase to around 8 EJ in biomass consumption for energy in 2030. The strategy assumes that most of the biomass used in the EU in 2050 will be produced within the EU, while only 4-6% will be imported.

4.3.2 Opportunities to increase the global resource

The amount of sustainable biomass can be increased if the productivity in agriculture and forestry is increased, and if land can be designated for afforestation without occasioning deforestation elsewhere in the world. A new report[61] predicts that more resource-efficient and less expensive processes for the industrial production of milk, meat, leather, etc. could relatively quickly replace traditional livestock

[56] IPCC: 2018 Global Warming of 1.5°C. An IPCC Special Report.
[57] 157 PJ solid biomass/5.8 million = 27 GJ. 75% = 20 GJ.
[58] "Biomassepotentialer i Danmark, EU og Globalt (Biomass potentials in DK, the EU and globally), University of Copenhagen and Cowi for the Danish Energy Agency 2015.
[59] Brief on biomass for energy in the European Union, The European Commission's Knowledge Centre for Bioeconomy, JRC, 2019.
[60] A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy Brussels, 28 November 2018. In-depth analysis.
[61] Rethinx, Rethinking Food and Agriculture 2020-2030, September 2019.

production. This could release a very considerable area of agricultural land for the cultivation of energy crops with a favourable climate profile.

Geological storage of CO_2 from biomass burning (bioenergy with carbon capture and storage, BECCS) could be necessary to meet mitigation targets. This could entail an increased consumption of biomass for energy. However, traditional BECCS is assessed to be energy-intensive and expensive. Several recent studies[62] identify a significant need for hydrogen to reach the goal of net-zero emissions in 2050. This potentially paves the way for considerably cheaper CO_2 storage[63].

4.4 Danish biomass resources

The energy potential of biomass and biogas produced in Denmark is assessed in the short term to be around 160 - 180 PJ, including biodegradable waste but excluding energy crops and so-called blue biomass in the ocean. Energy crops are farmed on agricultural land for energy purposes and consumed in Denmark almost exclusively in the production of biogas. The energy potential is greater than 180 PJ if land can be converted from production of food products or fodder to energy crops or forest land.

4.4.1 Danish Commission on Climate Change Policy

In 2010, the Danish Commission on Climate Change Policy estimated the total energy potential of Danish land-based biomass resources at 174 PJ, assuming no additional areas are designated for the production of energy crops, see Table 5.

Danish biomass fuels (PJ)	Exploitation 2008	Additional potential not area-requiring 2008-2050	Total resources
Straw	15	25	40
Wood	41	19	60
Waste (non-fossil)	24	8	31
Biogas	4	28	32
Other bioenergy	5	6	11
In total	89	86	174

Table 5 Energy potential in Danish land-based biomass. Source: Danish Commission on Climate Change Policy

4.4.2 The +10 million tonnes plan

The +10 million tonnes plan from 2012[64] suggested how domestically produced biomass could be increased without reducing food production. The project outlined two scenarios: a 'biomass scenario' which focussed on maximising biomass production, and an 'environment scenario' which included more environmental considerations. The measures proposed included efficiency improvements; conversion to cereals yielding more straw; improvement; use of fast-growing three species in forests; exploitation of biomass from edges of roads, water courses and catch crops; and conversion of 149,000 ha from cereal crops to energy crops.

[62] A clean Planet for all, European Commission 2018, Net zero; the UKs contribution to stopping global warming, Committee on Climate Change 2019.

[63] If hydrogen is produced through electrolysis of water, oxygen is released in the process. Oxygen can be used in oxy-fuel combustion of biomass, where the CO_2 generated can be separated, compressed and stored geologically using only low energy consumption. In this way the energy-intensive capture process in traditional carbon capture and storage (CCS), which can constitute up to 80% of the total costs of CCS, can be avoided.

[64] +10 mio. tons planen (+10 million tonnes plan), Morten Gylling et. al. University of Copenhagen, 2012, revised edition in 2016 with the same data basis the for biomass potentials. The data basis was obtained from "Biomasseudnyttelse i Danmark - Potentielle ressourcer og bæredygtighed" (Use of biomass in Denmark - potential resources and sustainability), Uffe Jørgensen et. al., Danish Centre for Food and Agriculture (DCA), report no. 033, 2013, and was converted to million tonnes dry matter.

In 2020, in the biomass scenario, the energy potential was 179 PJ excluding energy crops, but including waste, while in the environment scenario the potential was 161 PJ, see Table 6.

Danish biomass fuels (PJ)	2009	Biomass scenario 2020	Environment scenario 2020
Straw	29	62	59
Wood from woodlots, hedges and gardens	13	13	13
Wood from forests	17	26	16
Livestock manure	3	46	44
Energy crops[65]	3	88	67
Other bioenergy	0.00	9	7
In total	65	245	205
Total excluding energy crops, including 22 PJ waste	84	179	161

Table 6 Estimated potentials in the +10 million tonnes plan. Gylling, Morten et. al. University of Copenhagen 2012. Converted from tonnes dry matter assuming a calorific value of 18 GJ/tonne.

The biomass scenario assumed there would be a continued afforestation rate of 1,900 ha/year, while the environment scenario assumed afforestation of 4,500 ha/year, although not contributing to increased amounts of woody biomass until after 2020. The potential for increasing the amount of woody biomass is therefore fairly modest in the short term. In a longer time perspective, more could be produced.

In the +10 million tonnes plan, the potential for forest biomass was 2.1 million tonnes dry matter in 2100 in the biomass scenario (around 38 PJ), while it was 1.7 million tonnes dry matter (around 31 PJ) in the environment scenario. If we include woody biomass from woodlots, hedges and gardens, the maximum potential for woody biomass in 2100 is 51 PJ[66] in the biomass scenario, corresponding to an increase of 21 PJ relative to 2009, see Figure 19.

In 2013, the University of Copenhagen carried out an analysis of the opportunities for increasing the production of domestically produced woody biomass up to 2100[67]. The analysis showed that with an afforestation rate of 4,560 ha/year, more intensive production with nurse trees, and greater prioritisation of wood for energy, the annual harvest of wood for energy could increase to 46 PJ in 2050 and 73 PJ in 2100.

[65] Here, energy crops refer to biomass crops (grown on an additional 149,000 ha land), rape, willow and poplar, as well as grass from organogenic soils.
[66] Excluding willow and poplar cultivated on agricultural land and assuming a calorific value of 18 GJ/tonne dry matter.
[67] Muligheder for bæredygtig udvidelse af dansk produceret vedmasse 2010–2100 (Opportunities for sustainable expansion of domestically produced growing stock 2010 - 2100). Department of Geosciences and Natural Resource Management, University of Copenhagen, January 2014.

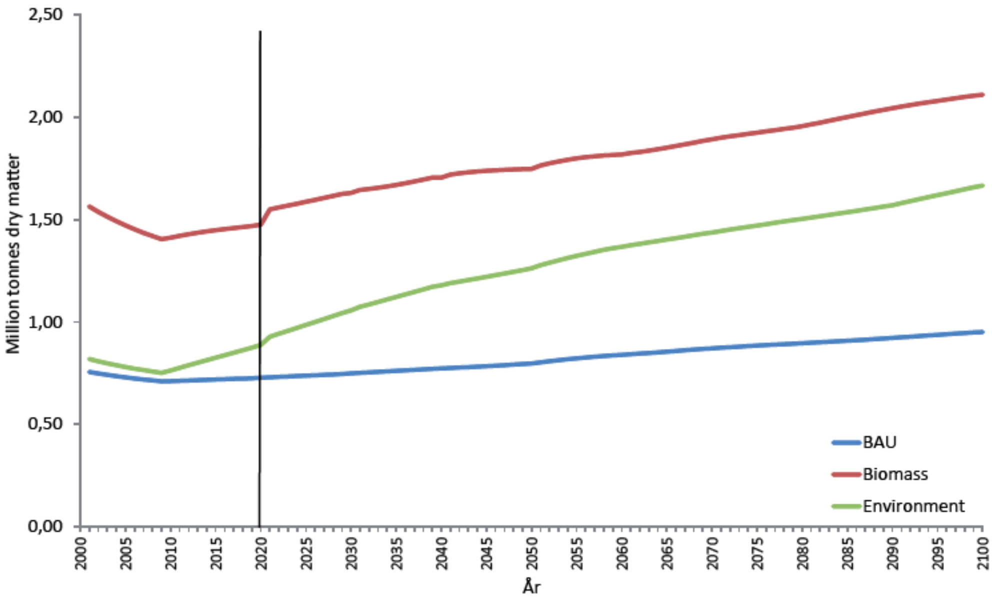

Figure 19 Development in available woody biomass for energy and materials in Denmark in the three scenarios. Source: The +10 million tonnes plan.

Thus, the maximum energy potential of biomass and biogas produced in Denmark is assessed in the short term to be around 160-180 PJ, including biodegradable waste but excluding energy crops and so-called blue biomass in the ocean. A consumption of 180 PJ corresponds to around 31 GJ per Dane, of which no more than around 10 GJ is woody biomass. If land is designated for cultivation of crops or wood for energy, the potential will be greater, however this requires converting land from production of food products or fodder to energy crops or forest.

Over time, Denmark could therefore meet its current biomass consumption with domestic resources, although this would require converting some of the consumption for imported woody biomass to residues from agriculture. Furthermore, it would require that several assumptions hold true, including successful efficiency gains, conversion to cereals with longer straw, increased collection of straw, increased use of fast-growing tree types, and more. These changes could take place in connection with establishing a biomass refining sector in which biomass can be refined into biological building blocks for use in bio-based products within fuels, materials, fodder and food products.

Case: Green grass-based biorefinery for the production of protein, green pellets and biogas

Grass is an example of a crop which could enhance harvestable yields (dry matter yield per hectare) in a Danish context. Grass cultivation has many socio-economic benefits for the aquatic environment, the climate and drinking water. To promote grass cultivation and to be able to harvest the socio-economic benefits, a bio-refinery sector will have to be established to turn the fresh grass into protein concentrate to replace soy protein; green pellets for cattle feed; and brown juice for biogas production. A demonstration facility was established at Aarhus University in 2019 and two prototype facilities are under construction. Financed under the public service obligation (PSO) funding scheme. In 2018, the National Bioeconomy Panel set a goal that, within a specific number of years, Denmark is to substitute up to one-third of its imported feed protein with domestically produced proteins. According to the National Bioeconomy Panel, this will be possible through increased use of perennial grasses and biorefining. The recommendations from the panel were followed up by an action plan on new, sustainable proteins by the Ministry of Environment and Food of Denmark in October 2018.

5. Sustainability criteria

There are currently no statutory provisions in Denmark, nor at EU level, for the sustainability of solid biomass burned for heating and electricity.

There are statutory sustainability requirements for biofuels for transport. These requirements were introduced in the EU as a consequence of the current Renewable Energy Directive[68]. The sustainability requirements for biofuels have been fully harmonised, which means the same requirements apply in all EU Member States.

In 2014, the Danish Energy Association and the Danish District Heating Association entered into a voluntary agreement[69] to ensure that biomass used by electricity and heating plants in Denmark lives up to a number of internationally recognised sustainability requirements.

The new Renewable Energy Directive II (RED II)[70], which is to be implemented into Danish law by no later than 30 June 2021, introduced common European sustainability requirements for solid biomass and biogas used for other energy purposes than transport. The Directive contains minimum requirements, but Member States can stipulate stricter requirements if they wish.

The sustainability requirements for woody biomass under the Danish sector agreement and under RED II are described below.

5.1 The Danish sector agreement

The Danish sector agreement covers all electricity and heating plants that use biomass in the form of wood pellets and wood chips. However, the agreement's documentation and reporting requirements apply only to plants with an output of more than 20MW. These plants must prepare annual reports subject to third-party approval.

According to the agreement, 90% of wood pellets and wood chips used must meet the requirements. The remaining 10% must meet the requirements of the agreement, but only have to document that the legality requirement has been met. The requirements under the agreement cover the following:

1. Legality
2. Protection of forest ecosystems
3. The productivity and ability of forest to contribute to the global carbon cycle must be maintained
4. The forest must be healthy and well-functioning
5. Protection of biodiversity, sensitive areas and areas worthy of preservation
6. Social and work-related rights must be respected
7. CO_2 emissions limits in the biomass value chain

[68]Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009.
[69]Brancheaftalen om sikring af bæredygtigt biomasse (Sector agreement to safeguard sustainable biomass) can be found (in Danish) at: https://www.danskenergi.dk/about-the-danish-energy-association/biomass-energy.
[70]Directive 2018/2001 of the European Parliament and of the Council of 11 December 2018.

8. Additional (voluntary) requirements targeted at the carbon cycle, maintainance of forest carbon stock, Indirect Land Use Change (ILUC) and Indirect Wood Use Change (IWUC)

CO_2 emissions and CO_2 reductions are estimated according to the same principles as in the Renewable Energy Directive, see below. Estimates include energy consumption in the value chain, i.e. energy consumption for harvesting, transport and processing of the biomass compared with a fossil reference. The CO_2 emissions from chimneys at power plants are not included, see the UN calculation guidelines. Thus calculated, the sector agreement's requirements for CO_2 emission reductions are set to 70% in 2015, 72% in 2020 and 75% in 2025. Reported CO_2 emission reductions at large plants in 2017 were between 75% and 95% compared with the fossil reference.

Documentation for sustainability can be in two ways: The biomass either has to be certified under the PECF, FSC or SBP certification schemes[71]. Or alternative documentation must be available which basically entails the same requirements, but which makes it less burdensome for small producers to meet the requirements.

Until 2016, the FSC and the PEFC were dominant, but the SBP has since been gaining dominance. In 2017, the SBP was responsible for 72% of certified biomass and 57% of total woody biomass received by large energy plants in 2018. A total of 28% and 22%, respectively, of total forest biomass was FSC or PEFC certified. Only 4% was documented through alternative documentation.

5.2 Sustainability requirements in the new Renewable Energy Directive

The sustainability requirements in the new Renewable Energy Directive comprise sustainability requirements for raw materials and requirements for greenhouse gas emission reductions (CO_2 requirements). The criteria apply irrespective of from where (geographically) the biomass originates.

According to Article 29 of the Renewable Energy Directive, solid and gaseous biomass fuels can only be counted towards renewable energy goals and in inventories, and can only receive financial support, if they meet the sustainability requirements for raw materials and CO_2 set out in the Article.

The requirements for sustainability of raw materials only apply to biomass used at installations with a total rated thermal input of at least 20MW for solid biofuels and 2MW for gaseous biofuels. The CO_2 requirements only apply to new installations with thermal input above the mentioned thresholds and which are established after implementation of the Directive. Member States can decide that more or smaller installations should be covered as well.

The Renewable Energy Directive II (RED II) stipulates different requirements for biomass from agriculture, agriculture residues, forest biomass, forest residues and industrial residues, see below. Woody biomass not originating from forests, nor from agriculture is not covered by the Directive's sustainability requirements.

Requirements for legality, forest regeneration and biodiversity
For forest biomass, the Directive's sustainability requirements for raw materials include requirements to ensure

- the legality of harvesting operations

[71] The PEFC (Programme for the Endorsement of Forest Certification) and the FSC (Forest Stewardship Council) are forest certification systems, according to which the forest must meet certain criteria for sustainable forestry. The Sustainable Biomass Partnership (SBP) was set up by European energy companies in 2013. The SBP does not certify the forest; rather the biomass producer. The SBP applies a risk-based approach and states methodologies for how to collate data on the raw material and data for use in calculation of greenhouse gas savings.

- forest regeneration of harvested areas
- that areas designated by law or by the relevant competent authority for nature protection purposes are protected
- that harvesting is carried out considering maintenance of soil quality and biodiversity
- that harvesting maintains or improves the long-term production capacity of the forest

The requirements can be met if the country of origin has relevant legislation and monitoring in place or if systems have been introduced at forest sourcing area level to ensure that requirements are met.

Requirements concerning LULUCF and forest carbon stocks
As a part of the sustainability criteria for raw materials, biomass must meet requirements concerning land use and forestry (LULUCF). There are two ways in which these requirements can be met: either a) or b) below:

a) if the country of origin is a party to the Paris Agreement, and

i) has submitted a climate change mitigation target to the UN in the form of a nationally determined contribution (NDC) covering LULUCF emissions which ensures that changes in carbon stock are accounted for in the country's commitment to reduce or limit greenhouse gas emissions

or

ii) has introduced laws to conserve and enhance carbon stocks and sinks and provides evidence that reported LULUCF-sector emissions do not exceed removals.

b. If the above is not in place, the requirements can instead be met if management systems are in place at forest sourcing area level to ensure that carbon stocks and sink levels in the forest are maintained, or strengthened over the long term.

Requirements for CO_2 savings
Requirements for CO_2 savings in the Renewable Energy Directive apply only to new installations above 20MW and 2MW, respectively The savings are calculated by aggregating emissions from harvesting, transport and processing of biomass, etc. and comparing the result with emissions from a fossil reference. When calculating emissions, the CO_2 emissions from burning biomass are set at zero. The CO_2 savings must be 70% for installations starting from 1 January 2021, and 80% for installations starting from 1 January 2026.

Documentation and monitoring
Among other things, the Directive requires that Member States ensure that economic operators submit reliable information regarding compliance with requirements and make data available to the Member State. The Member States must ensure an adequate standard of independent auditing of the information submitted, and this auditing must ensure, e.g. that materials are not intentionally modified or discarded so that the consignment or part thereof could become a waste or residue. Finally, the Member States must ensure that information about the geographic origin and type of raw material product per fuel supplier is made available to consumers on relevant websites and is updated on an annual basis.

5.3 Sustainability requirements and sustainability

The Renewable Energy Directive is to be implemented into Danish law by no later than 30 June 2021. Sustainability requirements can address various challenges with regard to the sustainability of using biomass for energy and can reduce the risk that biomass used for energy is produced unsustainably. For example, requirements for forest regeneration will help to ensure that forests harvested for energy purposes are being regenerated. Requirements that the country of origin is a party to the Paris Agreement and includes the LULUCF sector in progress towards meeting its mitigation target will help to ensure that biomass is imported mainly from countries that account for emissions in the LULUCF sector and that include these emissions in their mitigation targets. The requirement for CO_2 savings can moreover help prevent the use biomass linked to high emissions in the production chain.

Therefore, overall, sustainability requirements will help support and promote sustainable use of biomass from wood for energy.

Having said that, however, future legislative requirements for the sustainability of biomass will not be a guarantee for the sustainability of all Danish consumption of biomass. This is because certain aspects of sustainability cannot robustly be addressed through sustainability requirements for biomass. This includes aspects such as indirect market effects, indirect land use change impacts, maintenance of forest carbon stocks, and safeguarding biodiversity.

6. Existing and planned biomass support schemes

This chapter outlines existing and planned economic instruments targeting the use of biomass for electricity and heat production.

6.1 Support for existing CHP plants using biomass

Existing plants using biomass for electricity production can receive subsidies pursuant to section 45a or section 45b of the Danish Renewable Energy Act (the RE Act). These subsidy schemes were agreed as part of the 2018 Energy Agreement.

Non-written-off plants are subsidised pursuant to section 45a from 1 April 2019, while all other plants using biomass are subsidised pursuant to section 45b. Section 45a entered into force on 1 April 2019, while entry into force of section 45b is pending approval from the European Commission. The subsidy schemes replace the existing support pursuant to section 45 which entitled all biomass plants producing electricity to DKK 0.15/kWh. Section 45 was repealed as of 1 April 2019 with the expiry of the state-aid approval.

The purpose of sections 45a and 45b is to ensure that plants continue to use biomass and to provide a possibility for non-written-off plants that have invested in biomass conversion in good faith under the previous scheme to partly or fully write off their investments. If the new subsidy schemes had not been established, there would have been a risk that the plants discontinued producing electricity or went back to fossil fuels.

6.1.1 Section 45a: Support for existing, non-written-off biomass plants

Under section 45a of the RE Act, the Minister for Climate, Energy and Utilities may provide a price supplement for electricity produced from burning biomass. The supplement is DKK 0.15/kWh and the scheme entered into force on 1 April 2019. The price supplement can be paid for no more than 15 years from the time of conversion if the plant was converted to burning biomass, and for no more than 20 years from the time of establishment if the plant was established as a biomass plant or a multi-fuel plant.

In connection with reinvestment, until 1 April 2019, the Minister could extend the support periods referred to above by up to four years. The value of each reinvestment is calculated using straight-line depreciation over ten years. Investments that can be included in determination of the support period include investments that 1) extend the lifetime of the plant; 2) increase the capacity of the plant; and/or 3) mean the plant can produce electricity by burning additional types of biomass fuel.

The plants must have started supplying biomass-based electricity to the supply grid before 1 April 2019. In exceptional circumstances, up until 1 January 2020, the Minister could grant exemption from this requirement. Only one such exemption has been given, i.e. to the new unit 4 at Amagerværket.

Price supplements are only paid for the part of the electricity produced from biomass and not the electricity produced from other fuels in the plant's production. Biomass from household and commercial waste is not subsidised.

6.1.2 Section 45b: Support for written-off plants

For electricity produced at plants not covered by section 45a (i.e. already written-off plants, which had not invested sufficiently to be covered by the 15-øren (DKK 0.15) scheme etc.), the Minister may provide a price supplement per kWh corresponding to the additional cost of using biomass for electricity compared with a fossil reference. The supplement may not exceed a cap of DKK 0.11 per kWh. Plants that started producing electricity from biomass on 1 April 2019 at the latest are entitled to this price supplement.

The Minister issues rules on how to determine the supplement, and the Minister may issue rules changing the cap on the price supplement.

The rules on how to determine the price supplement have been laid down in an executive order. Separate subsidy rates are determined for wood pellets and for other biofuels, respectively. The rates are determined on an annual basis. For 2020, the rate for wood pellets is DKK 0.08/kWh, while for other biofuels it is DKK 0.00/kWh reflecting the situation that, in 2020, there are no additional costs of using these biofuels instead of coal in CHP production.

The scheme will not take effect until it has been approved by the European Commission. The scheme will cease after ten years.

6.2 Planned support scheme targeting new electricity capacity

The 2018 Energy Agreement allows for support to new electricity production based on biomass and biogas, provided these technologies can compete with other renewable technologies. A specific proposal for a support model has yet to be prepared.

Because biomass-based CHP production is assessed to be a relatively expensive technology, it is not very likely that new plants will be able to compete with other renewable technologies, although it is not entirely unlikely either.

6.3 The ‘basic amount’ scheme (support for the establishment of heat pumps, biomass boilers and solar heating)

Further to the 2018 Energy Agreement, DKK 540 million were set aside to manage the discontinuation of the basic amount scheme. Of the DKK 540 million, a total of DKK 111.4 million was later set aside for the years 2020 and 2021 for the establishment of electric heat pumps, solar heating systems and biomass boilers connected to the collective grid.

This pool will be distributed as direct support to district heating plants that have received the basic amount. Specifically, district heating plants will receive support to procure a production plant. All district heating plants in small-scale areas that have received the basic amount can apply for funds from the pool. However, this is provided the collective production plant (electric heat pump, solar heating system or biomass boiler) for which support is granted produces district heating and primarily (more than 50%) displaces existing district heating production based on fossil fuels.

With a pool of DKK 114.4 million and an expected maximum DKK 2 million per installed MW, the pool will likely be able to provide support for the installation of 57MW. However, it is not possible to know or predict anything about the breakdown of the MW installed between heat pumps, solar heating systems and biomass boilers. This will depend largely on the plant owners that choose to apply for subsidies, their existing production plants and on the physical possibilities provided in the local area in question. However, assuming around half of the pool’s funds will go to biomass boilers (i.e. wood chip boilers, in our case), this will lead to increased consumption of wood chips in the range of 50,000 tonnes annually.

6.4 Section 20b: including a profit in the price of heating

To promote district heating based on biomass and other renewable technologies, owners of biomass, biogas, geothermal and solar heating systems, and owners of electric heat pumps supplying heat to a collective heating system, can include a profit when setting the price of heat supplied from these systems. The profit serves as financial incentive to invest in renewable energy for district heating production.

6.5 Tax benefits and allocation of tax benefits

Biomass used for heat production is not subject to tax. This is in contrast to fossil fuels, which are subject to energy and CO_2 taxes, and electricity production, which is subject to an electricity tax. Fossil fuels used at large plants[72] are also subject to the EU Emissions Trading System (EU ETS), which means these plants must buy emission allowances corresponding to the plant's CO_2 emissions from fossil fuels for electricity as well as heat production.

The tax exemption for biomass makes it financially advantageous to use biomass in heat production. The exemption from paying for emission allowances is another advantage of using biomass in electricity production. Biogas, solar, wind, ambient heat, etc. also enjoy tax exemptions and biomass therefore has no tax advantages compared to these energy sources. However, biogas which is upgraded and added to the natural gas grid is subject to the same taxes as natural gas.

Table 7 shows the taxes, etc. imposed on various fuels depending on use.

	2020 taxes and emission allowance costs in DKK/kWh fuel or other energy source used			
Fuel / energy source	**Energy tax**	**CO_2 tax**	**Emission allowances[1]**	**Total**
Heat production:				
Coal	0.204	0.060	0.043	0.307
Natural gas	0.204	0.036	0.026	0.266
Electricity, heating purposes	0.210	0.00	0.00	0.210
Electricity, heating purposes, tax from 2021 cf. Energy Agreement	0.155[2]	0.00	0.00	0.155
Biomass and biogas	0.00	0.00	0.00	0.00
Solar heating, etc.	0.00	0.00	0.00	0.00
Electricity production:				
Coal	0.00	0.00	0.043	0.043
Natural gas	0.00	0.00	0.026	0.026
Biomass and biogas	0.00	0.00	0.00	0.00
Solar, wind, etc.	0.00	0.00	0.00	0.00

Table 7 Taxes and emission allowance costs for fuels and other energy sources in heating and electricity production, in DKK/kWh fuel or energy source used. Rates applicable for 2020, and 2019 prices of emission allowances.
[1] 2019 price. Costs vary with the market price of emission allowances.
[2] According to the Energy Agreement, the rate will be lowered to DKK 0.155/kWh from 2021.

The table shows a considerable tax advantage of using biomass for heat production compared with fossil fuels and electricity, even considering the tax reduction for electricity for heating purposes included in the Energy Agreement.

[72] Plants with a rated thermal input of at least 20MW. Smaller plants are not covered by the EU ETS, however they pay a CO_2 tax on the fuel they use in their electricity production.

Figure 20 shows taxes and emission allowance payments for energy sources in heat production.

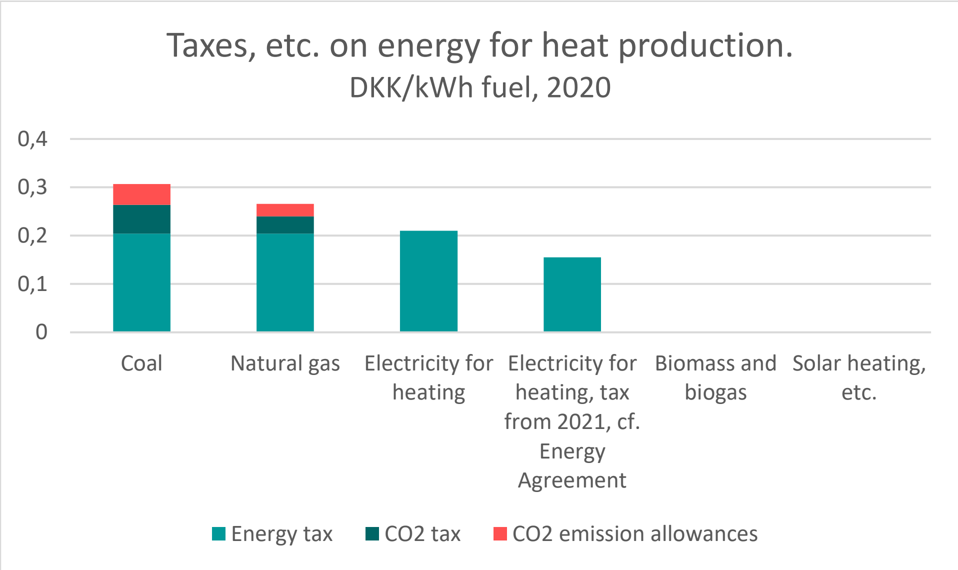

Figure 20 Taxes and emission allowance payments for energy sources in heat production.

Since there is no tax on fuels for electricity production, but only an emission allowance obligation, the emission allowance/tax advantage of using biomass is modest. In practice, electricity production takes place at CHP plants, which produce both electricity and heat, and therefore the emission allowance/tax advantage here lies in the combination of the advantages in electricity and heat production, respectively.

For a typical large-scale CHP plant using biomass instead of coal, the emission allowance/tax advantage can be estimated at around DKK 0.50/kWh electricity, or around DKK 0.30/ kWh heat. The advantage is therefore considerably greater than the direct support achievable for the use of biomass.

Up to 2012, the part of the tax advantage of CHP plants linked to heating production (i.e. the majority of the tax advantage) went to district heating end users, which meant there was no incentive for CHP plants themselves to convert their production from coal to biomass. The 2012 Energy Agreement gave large-scale power plants the possibility of divide their tax advantage such that some of the advantage went to electricity production. This change proved significant for the conversion of large-scale power plants to biomass because it made it advantageous for the plants to use biomass instead of coal. Consumption of solid biomass for electricity and heat production in Denmark has subsequently increased, from around 58 PJ in 2012 to an expected around 105 PJ in 2020[73].

The subsidy and tax levels in the energy area are also vital in determining which collective production plants are approved for establishment, see section6.3 on the current regulations. This is because operating costs play a significant role in determining what type of plant is financially most advantageous and therefore is most worthwhile investing in for heating supply companies.

The tax advantage linked to biomass has contributed to making collective heat production based on biomass significantly cheaper than heat production based on fossil fuels. So far, biomass has also led to cheaper heat compared with electric heat pumps.

[73] Source: Denmark's Energy and Climate Outlook 2019 (DECO19).

Until 2017[74], electricity consumption for heat production was subject to a relatively high tax on energy (the space heating tax) of around DKK 0.405/kWh, which was around two times that of the energy tax on fossil fuels (DKK 0.238/kWh). Furthermore, there was the cost associated with the PSO tariff, which was at around DKK 0.20-0.25/kWh at the time. This relatively high tax and tariff burden on electricity for heat production meant that, until very recently, electric heat pumps were only an attractive alternative to fossil fuels in collective heat production in exceptional circumstances, and they were never an attractive alternative to biomass-based collective heat production. The repeal of the PSO tariff[75] and the subsequent reduction in the tax on electric heating to DKK 0.155/kWh following from the 2018 Energy Agreement meant that electric heat pumps are now the cheapest alternative in collective heat production in the majority of situations.

For individual heat supply systems, the reduction of the tax on electric heating means that electric heat pumps are the cheapest solution in many situations. However, the bigger picture is more complex. Natural gas boilers may, in some situations, still be the cheapest solution for small households, and wood-burning stoves may be cheapest for consumers with access to cheap firewood.

[74] See Aftale om erhvervs- og iværksætterinitiativer 2017 (Agreement on business and entrepreneurial initiatives).
[75] See Aftale om afskaffelse af PSO-afgiften 2016 (Agreement on repeal of the PSO tax).

7. Effects of current regulation

This chapter describes the effects of current regulation in the heating area on heat production plants established in the Danish district heating network, as well as what plants can be established in the future. The chapter focuses on what has so far led to the widespread use of biomass we see today, and on how regulation is expected to influence the future use of biomass in heat production. After this, the chapter looks at the area restriction pertaining to district heating and natural gas areas, and at the conditions for expanding district heating areas so that they overlap with natural gas areas. Finally, the chapter outlines the regulation pertaining to individual heating systems, focussing on the opportunities for using biomass in this area.

7.1 District heating areas

The Danish district heating sector is regulated through the Danish Heating Supply Act and associated executive orders, including the Collective Heating Supply Projects Order. The Heating Supply Act addresses two overall concerns: a socio-economic concern (including environmentally friendly and energy-efficient use of electricity and fuels) and a consumer protection concern.

The Collective Heating Supply Projects Order regulates the municipal approval system for the establishment and conversion of installations for production and transport of district heating etc. The provisions of the Collective Heat Supply Projects Order refer to the socio-economic, environmental, and corporate/consumer financial concerns of the Heating Supply Act. Furthermore, the Order regulates which new collective heating plant projects municipalities can approve. In effect, the Order therefore determines which installations can be established and what types of fuel they may be designed for.

Box 1: Brief history of Danish heating planning

The first Danish Heating Supply Act was adopted in 1979. The purpose was to make Denmark less dependent on large oil imports and to enhance security of supply through use of domestic fuels, for example. The main tasks were to establish a large, nationwide natural gas grid, to establish district heating plants and district heating networks in a large number of municipalities, and to increase the use of waste heat from large-scale electricity plants.

The tasks were solved in a collaborative effort between central, regional and local governments, and implementation took place during the 1980s through municipal heating supply plans. The result was a division into areas supplied via district heating systems, areas supplied via natural gas systems and areas with no collective supply systems in place. District heating areas were further divided into areas with natural gas, areas with biomass, as well as large-scale areas with coal-based supply. A majority of district heating areas were based on natural gas.

In 1986, a 'cogeneration agreement' was established between the government and electricity plants. The agreement obligated electricity plants to establish 450MW electricity capacity at small-scale CHP plants based on domestic fuels.

In 1990, the government at the time and the Social Democratic Party concluded an agreement to further transform the Danish energy system into a more environmentally friendly system. The transformation was to be achieved by connecting more consumers to the collective supply system; converting plants to cleaner fuels; and converting district heating production to combined heat and power, where economically beneficial for society. Further to this, the second Heating Supply Act adopted in 1990 decentralised decision-making powers, e.g. through the Collective Heating Supply Projects Order from 1991.

Thus, small-scale district heating areas were divided into areas with natural gas and areas with biomass. As a result, the pattern of biomass consumption evident in small-scale areas today is largely the result of centralised planning. In 2019, all areas under 500 TJ came under a new type of regulation, see below. As a result, there are only 23 large areas left today, of which only three are biomass-based.

The natural-gas-based district heating areas, and the associated natural gas consumption, have so far been maintained because of the fuel obligation set out in the Collective Heating Supply Projects Order from 2004. In practice, the fuel obligation has served as a biomass ban (see box 4). The fuel obligation has meant that it has only been possible to establish very few biomass-based plants in natural gas areas. Electric heat pumps, solar heating and surplus heat have not been covered by this protection, but because heat pumps used to be uneconomic due to high taxes, deployment of heat pumps has only started to gain traction within the last couple of years.

Large-scale CHP plants have followed a significant trend of conversion from fossil fuels to biomass over the past ten years or so. This is clearly a result of incentives that were introduced with the 2012 Energy Agreement.

The Heating Supply Act also contains provisions on prices requiring that the price of heating be fair, and that the price may only be used to cover necessary costs for production and transport of heat, as well as returns on capital[76]. As mentioned in the previous chapter, owners of biomass production plants may also include a profit in the price of heating. The profit is only regulated by the general provision in the Heating Supply Act stipulating that the pricing of heating must be fair. This is enforced by the Danish Utility Regulator (DUR) in connection with complaints and similar according to the so-called substitution principle[77]. Furthermore, owners of large-scale CHP plants which have converted from coal to biomass can, in addition to the necessary costs of the plant, include a share of the biomass tax benefit. This share is negotiated with the buyer. The tax benefit is not subject to the fair pricing provision of the Heating Supply Act and is therefore also not subject to the Danish Utility Regulator's practice concerning the substitution price. The tax benefit is described in more detail in the previous chapter.

7.1.1 Types of area

The Collective Heating Supply Projects Order distinguishes between different types of district heating area, and different rules apply for the establishment of new plants depending on the type of area in which they are to be established. The Order distinguishes between four types of district heating area, see Figure 21.

[76] The Danish Utility Regulator has to approve the return on capital.

[77] The substitution price is the real, observed alternative price that buyers can get from another supplier, or the price at which buyers could produce the heat themselves.

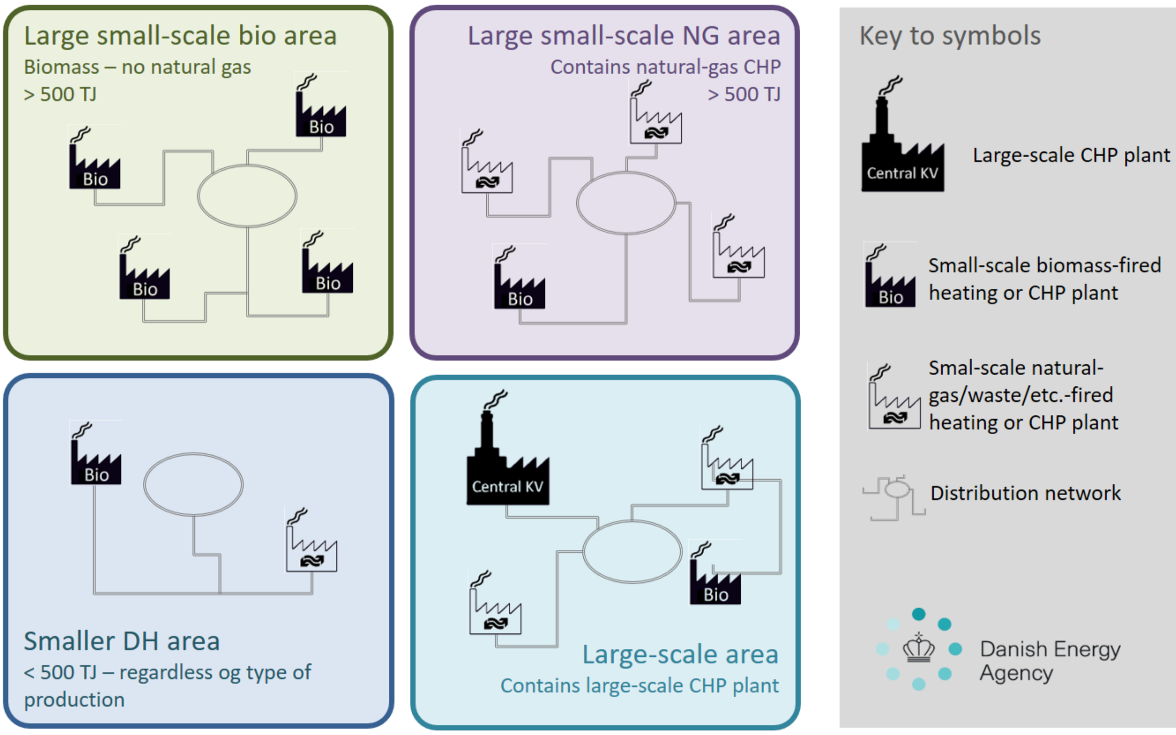

Figure 21 Types of area in district heating regulation in 2019. Until 1 January 2019, 'smaller district heating areas' were divided in the same way as the large small-scale areas, i.e. into biomass-based and natural-gas-based areas, respectively.

Table 8 List of types of main area, heating basis and consumers

Type of area	Number of areas	Heating basis PJ/yr	Number of consumers, standard households
District heating areas			
Smaller areas, < 500 TJ	385	[30.1]	360,000
Large natural-gas-based areas, > 500 TJ	[20]	[18.1]	[222,000]
Large biomass-based areas, > 500 TJ	[3]	[2.2]	[28,000]
Large-scale areas	13	83.8	1,029,000
Total	**421**	**Approx. 134**	**Approx. 1.6 million**

7.2 Possibilities for establishing new capacity in district heating areas

The possibilities for establishing new production plants vary from area to area for regulatory and practical reasons. This has been summarised in Figure 22 and is outlined area by area further below.

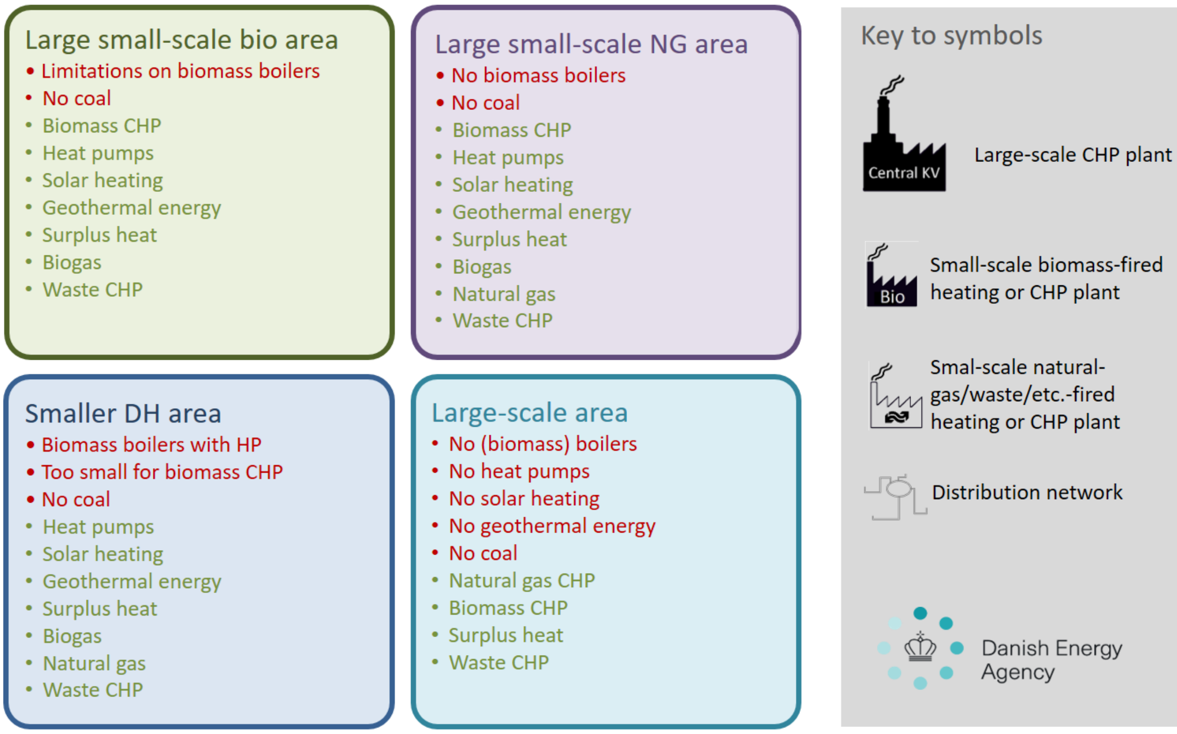

Figure 22. Options for establishing new production plants under Danish district heating regulation in 2019, by types of area.

In all types of district heating area, establishing, changing or closing production plants must meet the so-called socio-economic requirement, see the Collective Heating Supply Projects Order under the Heating Supply Act. Establishing, changing or closing plants with a rated power above 25MW are not covered by the Heating Supply Act and are approved in accordance with the Power Plant Order.

Box 2: The socio-economic requirement

A key concern in the Heating Supply Act is a socio-economic concern. The municipal approval system is therefore based on a requirement that projects have a positive socio-economic impact. According to this requirement, all project proposals for new plants must undergo a socio-economic assessment based on a cost-benefit analysis prepared according to the guidelines from the Danish Ministry of Finance and the Danish Energy Agency, and based on calculation assumptions published annually by the Danish Energy Agency. On the basis of the calculations, only the most socio-economically advantageous project among a number of relevant alternatives can obtain approval. The socio-economic requirement also applies to designation of new areas for collective supply (district heating or natural gas), and if a district heating network plans to expand into a natural-gas-supplied area.

On the basis of current calculation assumptions, the socio-economic requirement generally means that electric heat pumps typically perform better than biomass boilers, and that both technologies perform better than fossil fuels. In some situations, the requirement therefore prevents the establishment of biomass boilers. However, reinvestments[78] in existing biomass-based plants are assessed to be possible under the socio-economic requirement.

7.2.1 Smaller district heating areas < 500 TJ

The smaller district heating areas comprise a mix of biomass-based areas and natural-gas-based areas. The natural-gas-based areas were covered by the biomass ban up to 2019 in the form of an obligation to use natural gas (the fuel obligation). Following the 2018 Energy Agreement, the biomass ban in smaller areas was repealed to give plants more leeway. At the same time, a biomass approval system was put in place with requirements for the size of the expected savings for heating consumers in connection with the establishment of biomass boilers; the co-called consumer-financial requirement.

Box 3: The consumer-financial requirement for biomass boilers in smaller district heating areas

Following from the 2018 Energy Agreement, a special requirement was introduced in the smaller district heating areas for the approval of biomass projects based on the project's financial consequences for consumers.

According to the new rules, new biomass boilers may only be established if they give consumers an annual saving of DKK 1,500 per standard household compared with the socio-economically best alternative. In effect the requirement means that it is not permitted to establish a biomass boiler if it is practically possible to establish a heat pump, except for in exceptional circumstances when very cheap local biomass resources are available.

There is an exemption from the requirement if biomass boilers are established in combination with new or existing heat pump systems, provided the heat pump is larger than the biomass boiler. This means that it is permitted to establish biomass boilers for peak load production to supplement heat pumps.

The consumer-financial requirement and the exemption expire at the end of 2021. After this time, it is assessed that the socio-economic requirement will put a stop to the deployment of biomass in many of the situations in which a heat pump is a practical possibility. Exemptions to this could be very large plants or where the lifetime of existing biomass plants can be extended.

[78] In this context, reinvestments can be in the form of repair work on existing biomass plants or in the form of savings when establishing a new biomass plant in situations when other installations at the production facility, e.g. the chimney and storage facilities, can continue to be used.

In combination with the socio-economic requirement, the consumer-financial requirement means that in the smaller areas - also those which today are based on biomass - new biomass boilers may only be established if they are established together with electric heat pumps (which can supply the main part of the heat) or in special circumstances in which heat pumps are not practically possible.

In practice, the smaller areas (regardless of their current fuel base) are therefore subject to a ban on using biomass for peak load production, while it is permitted to supplement different types of heat pumps with biomass to meet peak load and reserve load.

However, it is assessed that reinvestments in existing biomass-based plants may be possible in some situations when the consumer-financial requirement ceases in 2021 (see box 3) - also under the socio-economic requirement.

7.2.2 Large small-scale areas

Today, large small-scale areas are still regulated differently depending on whether they are based on natural gas or biomass.

The few larger biomass-based areas in Denmark today have almost total freedom of choice, except for the socio-economic requirement which pushes them towards establishing heat pumps. However, it is assessed that reinvestments in existing biomass-based plants are possible, despite the socio-economic requirement.

In the natural-gas-based areas, the obligation to use natural gas applies, and in practice this means that use of biomass boilers is banned. In these areas, it is permitted to establish heat pumps, geothermal plants, solar heating, etc. but not biomass boilers.

Box 4: The natural gas fuel obligation (the biomass ban)

In the large small-scale areas (above 500 TJ) the fuel obligation applies if the area contains, or has previously contained, a natural-gas-based CHP plant.

According to the fuel obligation, fuel-based plants in natural gas areas may only use oil, gas and biogas. Because electric and solar heating systems are not fuel-based, the fuel obligation has no influence on the establishment of these installations.

The sole function of the fuel obligation is, in effect, to prohibit the establishment of biomass boilers (heat production alone based on biomass).

7.2.3 Large-scale areas

The large-scale district heating areas include the largest district heating areas in Denmark and are located in large urban areas.

In these areas, the large-scale CHP requirement applies, meaning there is an obligation in these areas to establish CHP plants when existing CHP plants need replacement (exploitation of surplus heat is however an exemption, see box 5). This prevents heat pumps, biomass boilers, geothermal plants, etc. from being established in these areas.

Box 5: The large-scale CHP requirement

Because of the CHP requirement in large-scale areas, all heat production plants, except for peak-load and reserve-load plants, are to be designed as CHP plants.

This means that, in large-scale areas, it is not permitted to establish installations designed for heat production alone, such as natural gas boilers, biomass boilers, heat pumps, geothermal plants, solar heating or similar. The only exceptions from this rule are the direct exploitation of surplus heat, and demonstration and development projects. Furthermore, to some extent, the Danish Energy Agency has a practice of granting exemption from the requirement in connection with exploitation of surplus heat via heat pumps, which is otherwise not permitted in large-scale areas.

As a result of the extensive conversion of large-scale power plants from coal to biomass in recent years, only three fully coal-fired CHP units exist in Denmark today. These units are in Esbjerg, Odense and Aalborg. The three units are expected to be phased out up to 2030, and Ørsted, who owns Esbjergværket, has been granted permission under the Electricity Supply Act to discontinue operations from early 2023.

Because of low electricity prices, it will most likely not be socio-economically wise to establish new CHP plants, although this is the only permitted solution in the large-scale areas. The Danish Energy Agency therefore assesses that exemptions from the CHP requirement may become relevant (see box 6). The exemption practice developed so far is expected to lead to the establishment of only the new capacity required to replace the coal units, and that priority should be on establishing as much capacity as possible as heat pumps, geothermal plants, surplus heat, etc., before permitting the establishment of biomass boilers. The socio-economic requirement is expected to support this prioritisation, even if the CHP requirement is repealed. However, no regulatory mechanism is in place to specifically prioritise plants on the basis of the fuel type used. However, it is assessed that reinvestments in existing biomass-based plants are possible, despite the socio-economic requirement. Furthermore, there are indications to suggest that biomass boilers at very large scales could perform better in socio-economic calculations than some heat pump projects, see chapter 7, and that in some situations local conditions may be such that biomass boilers could meet the socio-economic requirement.

Box 6: The future of CHP

Today, most of Danish biomass consumption for district heating production takes place at CHP plants in the large-scale district heating areas, see chapter 1. This is because the CHP requirement under the Heating Supply Act has meant that district-heating systems in large-scale areas had to be designed for combined heat and power production.

Because of low electricity prices, CHP plants can no longer achieve the same return on investment on plant capacity when trading on the electricity spot market. Among other things, this is reflected in the limited number of operating hours with electricity generation at large-scale natural gas plants; the challenged economy of gas-based CHP plants; and the fact that the most recently established CHP plants are designed with very little electricity capacity and a very large heat capacity.

In addition to low electricity prices and limited possibilities for earnings on capacity markets, etc., the discontinuation of subsidies for biomass-based electricity production (the 15-øren (DKK 0.15) scheme) further challenges investment in new CHP capacity.

Finally, the standardised costs allocation practice to be introduced as part of upcoming financial regulation of the heating sector is expected to undermine the business case of future investments in CHP plants, and possibly for some existing plants, depending on how the rules are phased in.

Therefore, it is assessed that there will be no business case for establishing additional CHP capacity up to 2030, and there will be no socio-economic benefit from doing so. To maintain security of supply in the heating sector, it is therefore necessary to permit the establishment of heating-only systems based on heat pumps, geothermal plants and biomass boilers in the large-scale areas.

Box 7: Exemption from the CHP requirement when phasing-out coal

In 2018, the Danish Energy Agency assessed that it was possible to grant exemptions from the CHP requirement if required by the phase-out of coal; if it is accordance with the socio-economic requirement; and if it does not negatively affect the security of electricity supply.

Overall, with this approach, heating systems such as heat pumps, geothermal plants and biomass boilers, could probably be established in the remaining coal areas to replace the production lost with the close down of coal units.

Because the socio-economic requirement typically prevents the establishment of biomass plants as long as heat pumps are a relevant alternative, exemptions will require that the socio-economic potential for heat pumps, etc. is exploited before the remaining capacity demand can be met by biomass.

7.3 Natural gas areas

Natural gas for heating is supplied through a collective system just as district heating, and parts of the natural gas supply is regulated by the Heating Supply Act. The regulation also shares many similarities with district heating regulation. Just as with district heating, the natural gas grid can be expanded on the basis of municipally approved project proposals for the supply of natural gas to new areas.

Once an area has been designated for district heating, natural gas supply cannot be established in the same area. This is referred to as ‘area restriction’. However, in some situations, the natural gas grid may be expanded with new connections, as long as these have not already been designated for district heating supply. The district heating network, on the other hand, can be expanded into areas supplied with natural gas. Such expansion is subject to approval by the municipality of a project proposal, including socio-economic calculations which must show that district heating supply is socio-economically more advantageous than both continued natural gas supply and transition to individual heating.

If an area is to be converted from natural gas supply to district heating, the local council must determine the compensation to be paid by the heating supply company to the gas distribution company. The compensation is to cover the lost opportunity to write off gas grid investments due to the decrease in gas supply. The compensation scheme ceases at the end 2020.

7.4 Individual heating

According to the building regulations, it is not permitted to install oil-fired boilers in new buildings. There are no direct restrictions on the installation of gas-fired boilers, but it is difficult to comply with the energy requirements (energy frame) for a new house with a gas-fired boiler. However, this depends on the overall assessment of the energy consumption of the building. The typical alternatives to fossil technologies are electric heat pumps, wood pellet boilers, wood-burning stoves and district heating. District heating is only an option if there is a district heating network in the consumer's local area, or a nearby network that can be expanded.

There are no direct, legal restrictions on the establishment of the technologies mentioned above. However, various regulations on the environment, noise, appearance, etc. may have influence on the establishment of these technologies. For example, it is assessed that the building regulations give preference to the use of on-premise heat pumps and solar heating rather than district heating in new buildings, because heat pumps and solar heating are more energy-efficient than district heating.

The use of wood-burning stoves and other firing installations with a firing capacity of up to 1MW is moreover regulated by the Statutory Order on Wood-Burning Stoves and the Environmental Protection Act. Neither of these laws make it possible to directly ban smaller firing installations; instead they aim at minimising pollution from the installations, e.g. through upper emissions limits for particles; a ban against using certain types of fuel; and specific requirements on chimneys. The Statutory Order on Wood-Burning Stoves moreover provides municipalities with the opportunity to limit the use of wood-burning stoves on the basis of a specific assessment.

Exemptions to the above are when consumers in areas with collective supply (natural gas or district heating) are obligated to use the collective grid and therefore often do not have the option of changing to other technologies. This applies in particular to large consumers, so-called group heating stations, such as schools and large housing associations, which are obligated to buy district heating or natural gas if they are located in a collective supply area. This obligation to buy prevents these consumers from establishing heat pumps or wood pellet boilers or using them or solar heating as a supplement to meet their heating demand.

8. Alternatives to biomass-based heat production

This chapter describes the alternatives to using biomass for heat production. In addition to current regulation, the technical possibilities for replacing fossil fuels and biomass, respectively, also depend on the area in which the heating system is located: i.e. a small or large district heating area (see Figure 20 in chapter 6), a natural-gas-supplied area or an individual heating area. There is special focus on the large-scale areas, because of the technological and resource-related challenges entailed by large-scale production.

8.1 Smaller district heating areas

Smaller district heating areas are seeing considerable deployment of electric heat pumps. These are primarily being established to replace natural gas at small-scale natural-gas plants (basic amount plants). The transition is mainly driven by a need to lower prices in connection with the phasing out of the basic amount scheme; by various subsidy schemes; and because, up to and including 2018, there was a ban against biomass in natural-gas-based areas.

As described in chapter 6, from 1 January 2019, regulations have meant that it is only permitted to establish biomass boilers in smaller district heating areas if they are established to supplement electric heat pumps that meet the baseload demand.

In the smaller district heating areas, it is technically/financially possible to supply around 80-85% of the heat from electric heat pumps, and these are often air-source-based or based on groundwater, wastewater or surplus heat.

The remaining 15-20% constitutes peak demand, and it is prohibitively expensive to meet this demand through heat pumps with the technology available today. In most places peak demand will continue to be met through natural gas, oil or biomass. Whether it can be met through biogas in the future depends on whether there is enough biogas in the gas system not destined for other purposes.

Except for the demand for peak load production, it is assessed that the smaller of the small-scale areas will generally be able to meet the heating demand without the use of biomass.

8.2 Large small-scale areas

The large small-scale areas in many ways resemble the smaller small-scale areas, because the socio-economic requirement (and, for the natural-gas-based areas, the fuel obligation) restricts the possibilities for establishing new biomass-fired installations.

As in the smaller areas, the possibilities for establishing heat pumps to supply the main part of the annual production (around 85%) are relatively good. However, most large small-scale areas have waste incineration, which typically supplies all of the heating in those months where heat pumps using ambient heat are most efficient. Challenges also exist in terms of whether there are heat sources available to provide enough heat for heat pumps established in the largest of these areas. This aspect is addressed in more detail in the section on large-scale areas.

For peak load, plants in the large small-scale areas can either use gas (natural gas shifting to biogas) or biomass.

8.3 Large-scale areas

As outlined in chapter 6, it is not permitted to establish heating-only systems, such as heat pumps or biomass boilers in large-scale areas. Because of the poor business case for CHP investments in the near future (see box 6), it is therefore assumed that it will be possible to permit alternative, heating-only production plants.

The large-scale areas have high heating demand and high heating density (the heating demand is distributed across a relatively small area), and the prices of properties are relatively high compared with smaller urban areas.

So, while a heat pump at one of the smaller small-scale district heating plants can be as little as 0.5MW, several hundred MW are needed to replace just a single large-scale CHP unit. This difference of scale is a significant challenge for heat pumps for several reasons:

- Limited access to heat sources on a large scale (geothermal energy, seawater, wastewater, air, surplus heat).
- A lack of examples of heat pumps used on a large scale in Denmark.

8.3.1 Access to heat sources

Heat pumps require access to a heat source, in small-scale areas typically air. Very large heat pumps are difficult to build with air as the heat source, especially if they are to meet considerable shares of the heating demand in large-scale areas and possibly also in the larger small-scale areas. This is because the land required for air coolers and the noise from the air coolers are assessed to make heat pumps disproportionally expensive in this type of area. Alternatives to air include wastewater, surplus heat, seawater, possibly groundwater, and geothermal energy.

It is assessed that wastewater, groundwater and surplus heat are not readily available in large-scale areas in quantities that will be able to meet all of the heating demand. For geothermal plants, there is a lack of successful demonstration projects in a Danish setting and so there are still major risks associated with establishing and operating geothermal plants in Denmark. Seawater heat pumps are a relatively untested technology, much dependent on local conditions such as seawater temperatures, sea depths, sea currents, salinity, etc. There are two smaller demonstration plants in Denmark today; however, it is unclear to what extent seawater heat pumps can contribute to meeting any considerable share of the heating demand in large-scale areas and in the larger small-scale areas.

8.3.2 Lack of examples of heat pumps used on a large scale in Denmark

Heat pumps on a large scale have yet to be established in Denmark, and large seawater heat pumps in neighbouring countries are based on refrigerants, which is not permitted in Denmark[79].

Currently, ammonia may be used as a refrigerant in heat pumps on a large scale. However, it is not permitted in Denmark to use synthetic refrigerants, which can cause high greenhouse gas emissions if there are leaks. Such refrigerants are permitted in other countries but are being phased out in the EU. Restrictions on the use of this type of refrigerant also mean that certain high-efficiency heat pumps cannot be used in Denmark. A new group of synthetic refrigerants (HFOs) with a low environmental impact is under development, and these refrigerants are therefore not subject to any restrictions. The new refrigerants can be used in high-efficiency installations but only one plant below 1 MW is known to be using them. Furthermore, at this point in time, these refrigerants are expensive and are produced only in limited quantities.

In the largest small-scale areas, and in large-scale areas in particular, there is doubt as to whether technologies such as heat pumps, surplus heat and geothermal plants will be able to meet the total heating demand, even in the years up to 2030. It is not deemed likely in the short run. In Odense and Esbjerg, investing fully in heat pumps is still not considered an option, because the technology used for biomass is more mature on a large scale, and because the geothermal resources are not deemed to be available in those areas. Instead, focus is on a model involving the establishment of natural-gas-based heat production for a transitional period. In both areas, it is expected that some biomass consumption will still be necessary to meet some of the heating demand.

8.4 Individual heating

The following outlines various bio-based, individual heating technologies as well as non-fossil alternatives to these technologies. For some of these technologies, the socio-economic as well as the consumers' costs are presented.

8.4.1 Overview

Table 9 shows the heating technologies used for heating individual houses in Denmark. Heating technologies with very poor deployment, e.g. petroleum stoves and wood-chip-fired stoves have been

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[79] It is permitted to use up to 50 kg HFCs as refrigerants in certain heat pumps.

omitted. For each heating technology, the table lists whether the technology typically meets the total heating demand or is used as a supplement.

Heating technology	Meets total heating demand	Supplemental heat source
Fossil fuels		
Oil-fired boiler	x	
Natural gas boiler	x	
Renewable fuels		
Wood-burning stove and fireplace insert	x	X
Fireplace		X
Wood pellet boiler	x	
Straw-fired boiler	x	
Fuel-free[1]		
District heating	x	
Heat pump	x	
Electric heating	x	X
Solar heating		X

Table 9 List of heating technologies

[1] **Meaning fuel-free at the consumer, i.e. including heating technologies that use electricity and district heating.**

8.4.2 Review of heating technologies

Natural gas boilers are widely used today, and oil-fired boilers are used to some extent. Both technologies require water-based heating systems. There is a ban against installing oil-fired boilers in new buildings, and both oil and natural gas are subject to high taxes on energy and CO_2 emissions.

There is a very large consumption of firewood in individual houses, and a large number of wood-burning stoves. In most situations, wood-burning stoves are used as supplemental heating, however in houses without water-based heating systems, wood-burning stoves meet the total heating demand or constitute the primary heating technology, e.g. in combination with electric heating.

The financial aspects of wood-burning stoves meeting total heating demand have not been estimated, because this technology supplies heating to houses without water-based heating systems, which makes comparison with the remaining alternatives difficult. Nor have the financial aspects of wood-burning stoves used as a supplemental heat source been estimated, because in these situations wood-burning stoves are typically chosen for comfort reasons and not out of financial concerns.

Fireplaces primarily supply 'comfort heating' and no financial estimate has therefore been performed for this type of heating technology.

Wood pellet boilers today are almost as widespread as natural gas boilers (in terms of total energy consumption; not in terms of numbers). A wood pellet boiler typically supplies heating to a water-based heating system. The financial aspects of wood pellet boilers have been estimated.

The use of straw-fired boilers for individual heating systems is not very widespread. Straw-fired boilers are typically used at farms where there is easy and presumably cheap access to straw. Because this type of heating technology is not very widespread, the financial aspects of its use have not been estimated.

District heating is an obvious alternative to biomass (and fossil fuels) in areas where district heating is available. The financial aspects of this heating technology vary considerably between district heating areas.

Heat pumps are also an obvious alternative to biomass (and fossil fuels). There are several types of heat pump:

- An air-to-air heat pump extracts heat from the outside air and emits heat in the form of hot air inside the house. This type of heat pump is typically used in houses that do not have a water-based heating system.
- An air-to-water heat pump extracts heat from the outside air and emits heat in the form of hot water inside the house. This type of heat pump requires a water-based heating system.
- A ground-to-water heat pump (ground source heat pump) absorbs heat from underground pipes and emits heat in the form of hot water inside the house. This type of heat pump requires a water-based heating system.

Heat pumps that extract heat from the air were previously very inefficient. However, this technology has been improved considerably in recent years, and today this type of heat pump is therefore an efficient technology for heat production. For houses with water-based heating systems, the typical choice would be an air-to-water heat pump, and the financial aspects of this technology have therefore been estimated.

Direct electric heating may be relevant for low-energy houses with only limited heating demand and as a supplemental heat source, e.g. in combination with a wood-burning stove.

Solar heating systems can meet some of the demand for domestic hot water during the summer but can typically only meet a limited share of space heating demand, because solar radiation is too limited during the winter to meet the heating demand. No financial estimate has therefore been performed for this type of heating technology.

8.4.3 Socio-economic costs

Figure 23 shows the socio-economic costs in DKK per MWh of heating supplied for the following technologies: Wood pellet boiler and air-to-water heat pump. For comparison, the socio-economic costs are shown for the fossil alternatives: oil-fired boiler and gas-fired-boiler.

Because it is difficult to determine the actual emissions of CO_2 from biomass, see section 3.4 above, CO_2 emissions and their associated cost have not been included in the estimates. This applies to all the technologies shown.

The figure shows that, from a socio-economic perspective, the heat pump is significantly cheaper than the renewable alternative in the form of a wood pellet boiler.

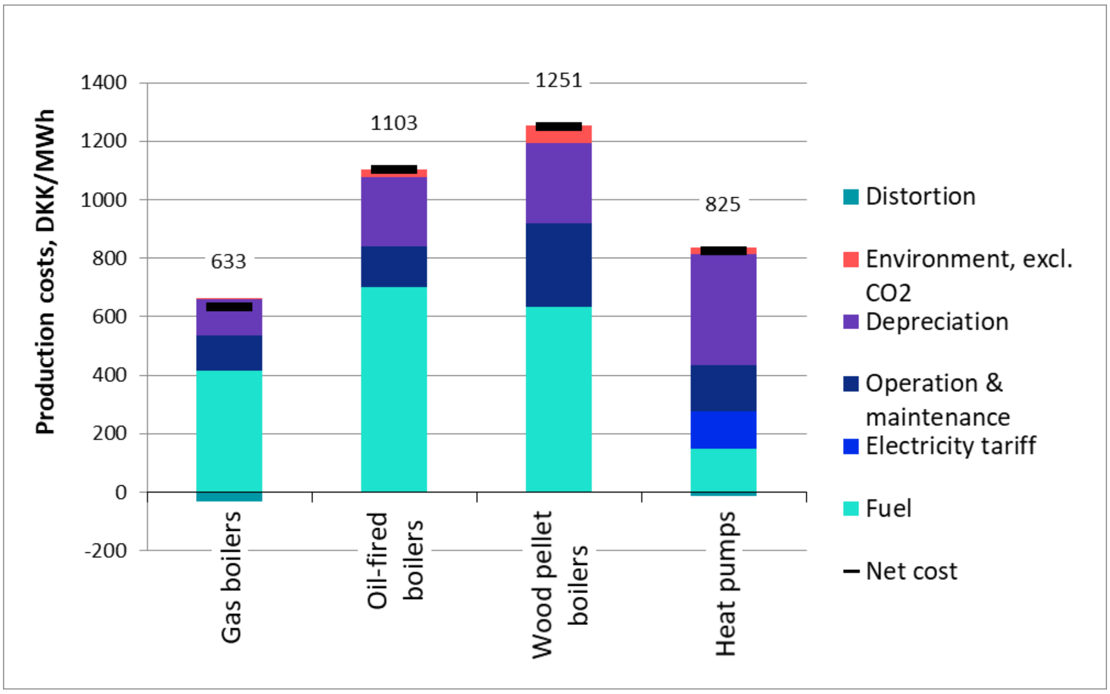

Figure 23 Socio-economic costs in DKK per MWh of heating supplied from technologies for individual heating. Assumed net space heating demand per unit: 18.1 MWh/yr (65 GJ/yr).

The values shown in Figure 23 are based on a standard heating demand for a single-family house of 18.1 MWh/year (65 GJ/year). However, since houses with wood pellet boilers are typically larger than average, an alternative calculation was made which assumed a heating demand of 26.9 MWh/year (97 GJ/year)[80]. The results of this calculation are shown in Figure 24.

In situations with large heating demand, the heat pump is also considerably cheaper than the wood pellet boiler.

[80] Based on data from Energy Statistics 2018.

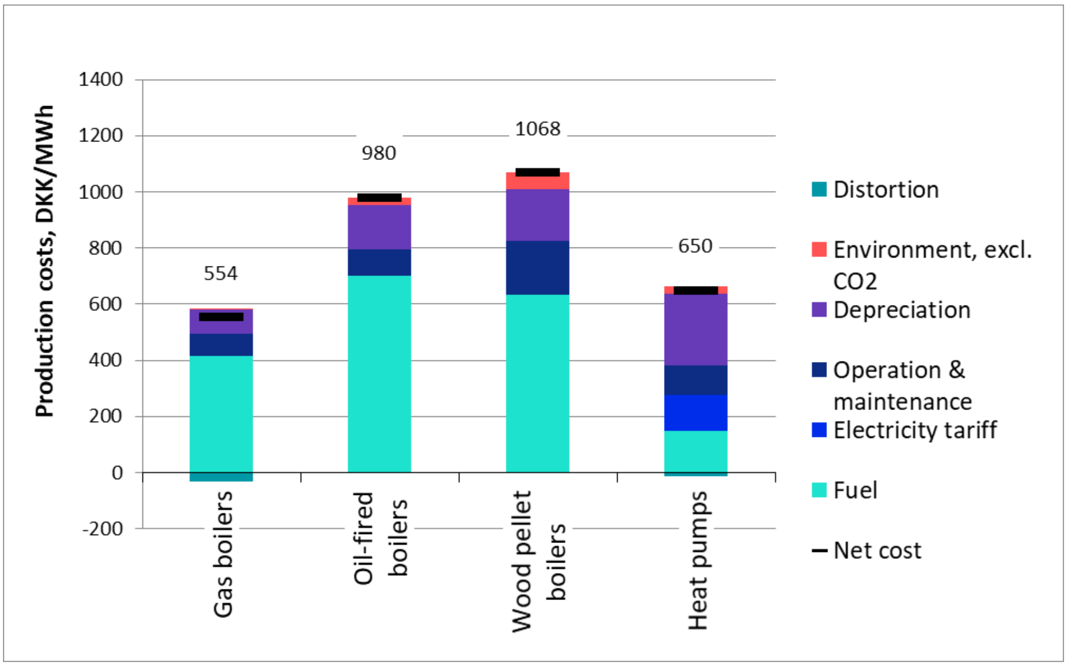

Figure 24 Socio-economic costs in DKK per MWh of heating supplied from technologies for individual heating. Assumed net space heating demand per unit: 26.9 MWh/yr (97 GJ/yr).

Consumers' costs

Figure 25 and Figure 26 show the financial costs for users in DKK per MWh heating supplied for the same technologies for houses with a standard heating demand (Figure 25) and for houses with a higher heating demand (Figure 26).

It appears that, also from the perspective of consumers' costs, the heat pump is cheaper than the wood pellet boiler. The heat pump is moreover cheaper than the gas-fired boiler and the oil-fired boiler because gas and oil are heavily taxed.

However, heat pumps are also subject to some taxation in that the electricity they use is subject to a tax on electric heating.

Although the heat pump is still cheaper than the wood pellet boiler, the electricity tax means that the financial saving for the consumer choosing the electric heat pump is not as great as the socio-economic saving.

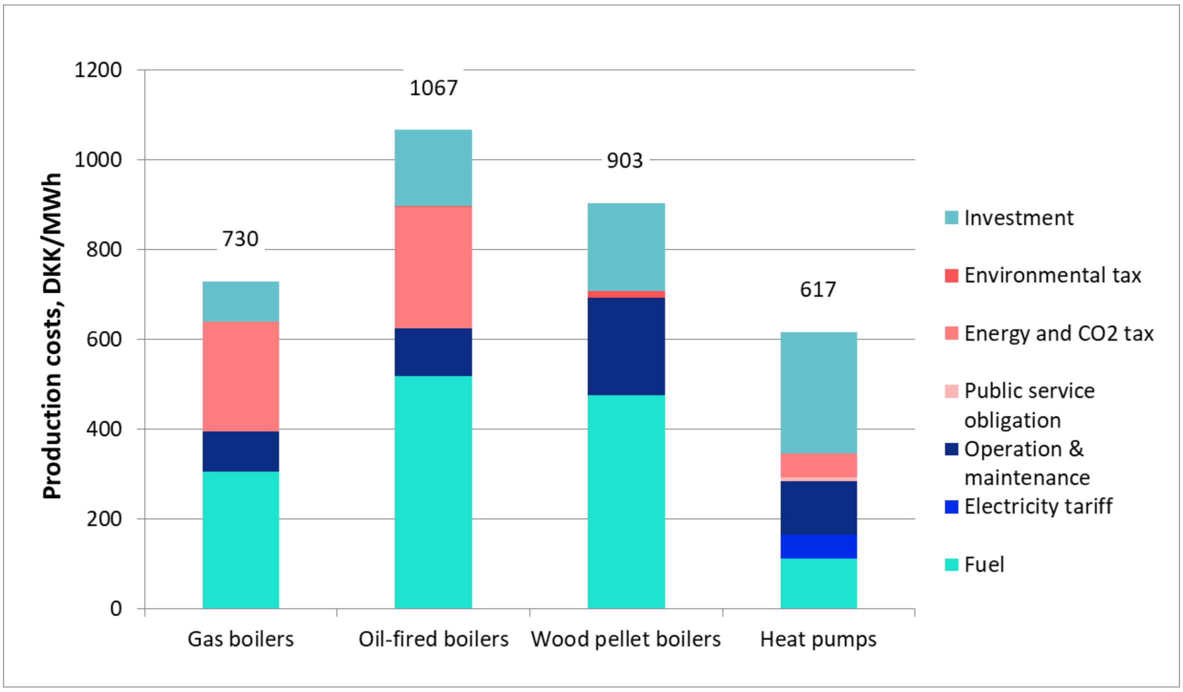

Figure 25 Consumers' costs in DKK per MWh of heating supplied from technologies for individual heating. Assumed net space heating demand per unit: 18.1 MWh/yr (65 GJ/yr).

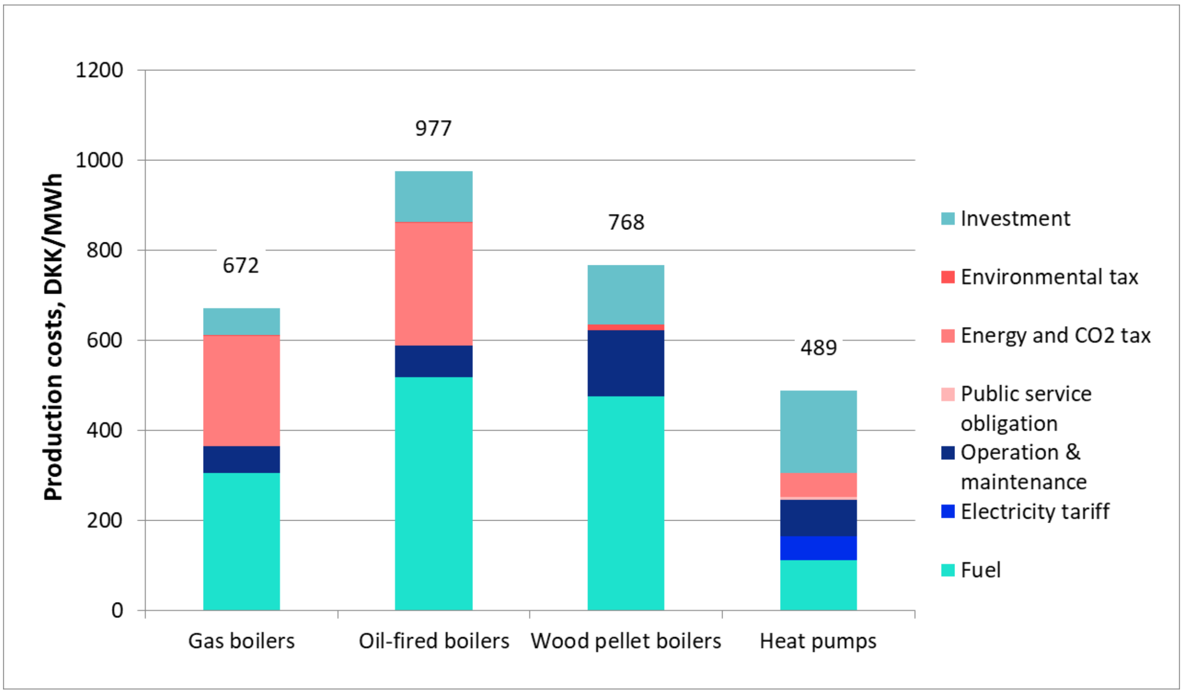

Figure 26 Consumers' costs in DKK per MWh of heating supplied from technologies for individual heating. Assumed net space heating demand per unit: 26.9 MWh/yr (97 GJ/yr).

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