Climate status and projection 2023 (KF23): Electricity and district heating (excl. waste incineration)

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This sector memo is part of the Climate Status and Projection 2023 (KF23). KF23 is a so-called frozen policy projection, which means that the development in the projection is conditional on a "politically frozen" absence of new initiatives in the climate and energy area beyond those decided by the Danish Parliament or the EU before January 1, 2023 or as a result of binding agreements. The KF23 results and the underlying analyses in the sector notes must therefore be seen in this frozen policy context. For further information on the frozen policy approach, see the KF23 sector memo Principles and Policies chapter 1 Principles for frozen policy.

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1. KF22 process: Status and projection to 2035

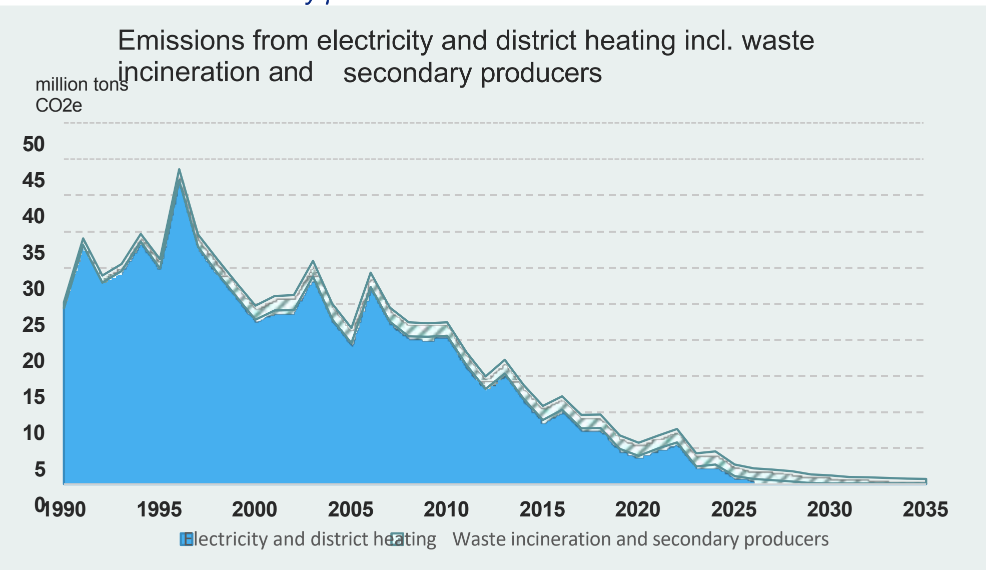
This note deals with the development in the electricity and district heating sector. The sector includes the majority of the plants that supply the Danish society with electricity and district heating, including e.g:

- Large and small CHP plants that supply both electricity and district heating
- wind power plants and photovoltaic plants that only supply electricity
- boilers, solar thermal systems, waste heat plants and heat pumps that only supply heat to district heating systems.

Although waste incineration plants also supply electricity and district heating, they are not included in KF23 as part of the electricity and district heating sector, but are treated as part of the waste sector (see KF23 sector note 9A - Waste incineration). For the sake of completeness, the development of greenhouse gas emissions from the electricity and district heating sector including waste incineration and secondary producers[1] is nevertheless shown in this memo. The consumption of waste for electricity and district heating production is also included in the calculation of the energy consumption of the electricity and district heating sector.

The development in greenhouse gas emissions from the electricity and district heating sector, including waste and secondary producers, is shown in Figure 1.

Figure 1: Emissions from the electricity and district heating sector including waste incineration and secondary producers.



Note: A figure showing the sector's emissions by fuel type can be found in the appendix at the end of the paper.

[1] Secondary producers do not have the production of electricity and/or district heating as their primary purpose. In accordance with the UN calculation rules, the emissions from secondary producers' electricity and district heating production are placed under the sectors to which the producers belong (e.g. manufacturing, trade and services, agriculture, etc.)

From 1990 until today, the production of electricity and district heating has moved from being a sector with high CO_2 emissions to today having a significantly smaller climate footprint. In the projection period up to 2035, this development is expected to continue, and in the absence of new initiatives, emissions from electricity and district heating production (excluding waste incineration and secondary producers) are expected to be 0.14 million tons in 2030, which corresponds to a reduction of more than 99% compared to the 1990 level. Emissions in the years after 2030 are expected to remain largely constant and are projected to be around 0.13 million tons in 2035.

Whereas in 1990 the electricity and district heating sector was a significant part of the climate challenge, in the future it will be seen more as part of the solution, as electricity and district heating produced on the basis of renewable energy is expected to play an important role in reducing the climate impact from other sectors, e.g. through electrification of transportation, heating and industrial processes and through expanded use of district heating in buildings previously heated by natural gas.

In a long-term climate perspective, the challenges for the sector are therefore more about how and to what extent it will be able to supply electricity and district heating at the times and in the quantities needed, and what resources, both financial and natural, e.g. in the form of land and raw materials, this will require.

However, the stronger link between the electricity and district heating sector and other sectors, combined with the key role that fluctuating renewable energy from solar and wind will play in electricity and district heating production, suggests that this challenge must be tackled in an interaction between all the sectors involved, e.g. through increased flexibility on the consumption side. The total electricity consumption and its composition is described in more detail in KF23 sector memo 8B.

The main difference between last year's climate projection, KF22, and KF23 is that Energiø Bornholm is included in the KF23 baseline. *Supplementary Agreement on Energy Island Bornholm 2022 of August 29, 2022 is* included in the KF23 baseline.[2]

In addition, it should be noted that the agreement on the Energy Island North Sea and additional 4GW offshore wind based on the *Climate Agreement on Green Power and Heat 2022 of June 25, 2022 is* not included in the KF23 baseline. Areas are offered on the assumption that the offshore wind farms do not negatively impact state finances over the project period and that there is space in the grid to the relevant extent. However, model runs with the final assumptions of KF23 show that with the other assumptions for the projection

[2] It should be noted that through the *Supplementary Agreement on Energy Island Bornholm, the* capacity, interconnections and grid connection for the park were agreed. In addition, support requirements (or risk hedging) were made possible in the event of negative project finances, which means that further political decisions, e.g. regarding financing and final stop-

go decision, are necessary to ensure establishment. financing and final stop-go decision, are necessary to ensure establishment. KF23 also describes an alternative course of action where Energiø Bornholm is not included.

current assumptions, there is not the necessary space in the electricity market to accommodate an additional 4 GW of offshore wind from the Climate Agreement on Green Power and Heat of
June 25, 2023, if otherwise the farms from previous agreements are assumed to be established and commissioned before (as described in more detail in the KF23 sectoral assumptions memo on electricity and district heating - offshore wind). Instead, the North Sea Energy Island and the additional 4 GW of offshore wind are included in a partial alternative scenario for the expansion of offshore wind.

2. Analysis of the KF23 process

2.1 Overall development in the sector up to 2035

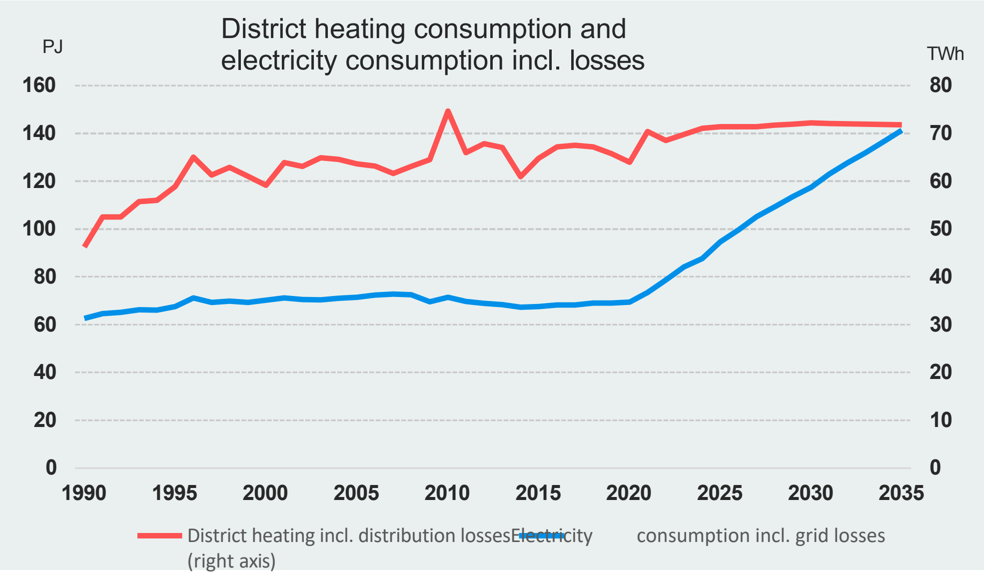
Activity in the electricity and district heating sector

The Danish production of electricity and district heating has originally been closely linked to consumption. For district heating, despite a small import of district heating across the Danish-German border, this is also the case today and is expected to remain so in the future.

For electricity, the situation is completely different. For many years, Denmark has had strong electricity connections to our neighboring countries, and the Danish electricity sector is highly integrated into the Northern European electricity market. While the development in activity in the district heating sector can be reflected 1:1 in the development in district heating consumption, the picture is different in the electricity sector. Market conditions as well as weather fluctuations, such as precipitation, temperature and wind conditions, cause shifts in which plants are producing and which are idle, and whether these are located in Denmark or in our neighboring countries, leading to periods of net import and periods of net export of electricity. However, domestic electricity consumption, both historically and - expectedly also in the future - has a significant influence on the activity in the electricity sector and the sector's greenhouse gas emissions.

Figure 2 shows the development in district heating consumption incl. distribution losses and electricity consumption incl. grid losses up to today and in the projection period up to 2035, in the absence of new initiatives.

Figure 2: District heating consumption incl. distribution losses and electricity consumption incl. grid losses. District heating consumption is calculated in PJ,



A relatively strong expansion of district heating in the 1990s has been replaced in the last twenty years by weak growth, which is expected to continue until 2035. The future development covers, among other things, two opposing trends. On the one hand, district heating is expected to expand to cover new areas, primarily through the conversion of areas previously supplied with natural gas, but at the same time, heat consumption in existing district heating areas is expected to decrease due to increasing energy efficiency in the building stock. District heating consumption is thus expected to increase from 128 PJ in 2020 to 144 PJ in 2030, which corresponds to an increase of 13%. Consumption is then expected to remain fairly constant until 2035.

As described in more detail in KF23 sector memo 3A Households, the starting point is the existing district heating and natural gas areas and it is assumed that natural gas areas will not be expanded. On the other hand, a gradual expansion of district heating areas is expected - especially in areas with a close connection to existing district heating supply. KF23's projection of district heating consumption is also based on the assumption that all the funds in the politically allocated pools for the conversion of oil and gas boilers are used. It should be emphasized that there is significant uncertainty associated with the phasing out of natural gas, as this will be driven by the municipal heating planning, which is still ongoing. The effect will be examined in more detail towards 2024.

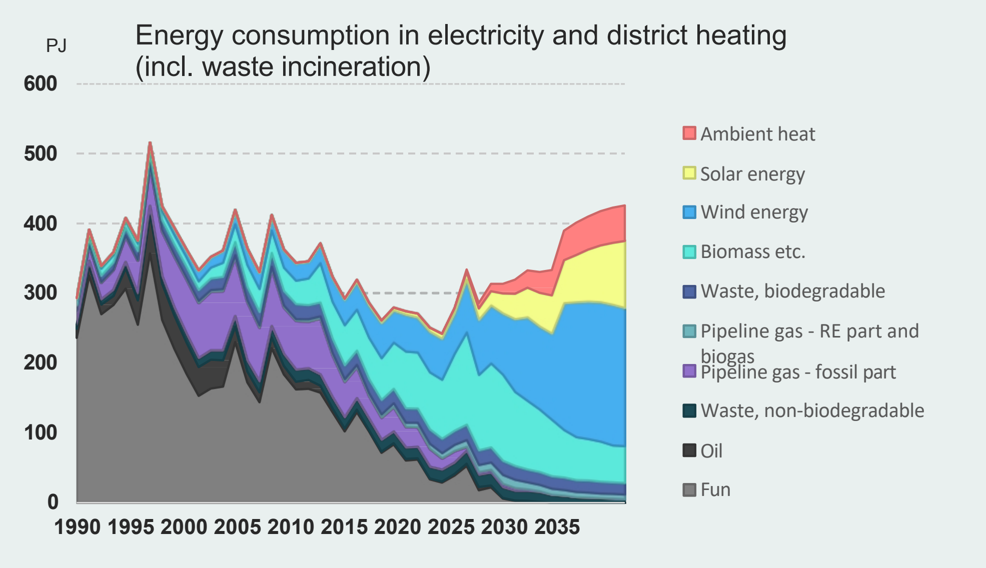
Electricity consumption also increased slightly in the 1990s, but since then has remained at a relatively constant level until today, although it showed a moderate increase followed by decreases in the years before and after the 2008 financial crisis. In contrast to district heating consumption, electricity consumption is expected to increase significantly in the projection period up to 2035. Electricity consumption is thus expected to increase from just under 35 TWh in 2020 to just under 59 TWh in 2030, corresponding to an increase of 69%, and towards 2035 to increase further to just under 71 TWh, corresponding to more than a doubling compared to 2020. For a more detailed description of the expected development in electricity consumption, see KF23 Sector note 8B Electricity consumption.

For the historical period, figure 2 also shows how weather fluctuations have had an impact on district heating consumption, while historically it has not affected electricity consumption significantly. As an increasing share of heat consumption will be produced using heat pumps, it is to be expected that electricity consumption will also be affected by weather fluctuations to a greater extent. However, this has not been analyzed further in connection with KF23. The projection is based on a normal climate year and therefore does not take weather fluctuations into account, but a partial sensitivity to weather fluctuations and derived effects on the sector's emissions is presented in section 3.2 Uncertainty and sensitivity calculations.

Technological development in the electricity and district heating sector

The reason for the sharp drop in emissions from the electricity and district heating sector from the mid-1990s to 2035 is not due to a decline in activity in the sector, but rather a fundamental change in the way electricity and district heating are produced. This is illustrated in Figure 3, which shows the development in the sector's energy consumption by energy type.

Figure 3: Energy consumption in the electricity and district heating sector by energy type (incl. waste incineration).



The electricity and district heating sector is characterized by an almost complete transition to renewable energy, especially as a result of the phasing out of coal-fired CHP at central plants, conversion to biomass, significant reduction of natural gas-fired CHP production and continued expansion of offshore wind, onshore wind and solar PV. The consumption of fossil fuels (incl. waste) for electricity and district heating production is expected to be reduced by 81% in 2030 compared to 2020, and a further reduction is expected by 2035 of 91% compared to 2020. It is expected that the consumption of non-biodegradable waste will be reduced by approx. 40% in 2030 compared to 2020, and reduced by approx. 70% in 2035 compared to 2020. If the consumption of fossil fuels excluding waste is assessed, a reduction of 99% is expected in 2030 compared to 2020, remaining at approximately the same level in 2035. Coal-based electricity and district heating production is expected to cease with the closure of Nordjyllandsværket at the end of 2028 (cf. KF23 Sector Assumptions Memorandum for Electricity and District Heating, chapter 8 Thermal production capacity), thereby fulfilling the target of phasing out coal by 2030 (KEFM, 2018). In addition, natural gas-based electricity and district heating production is expected to cease at the end of 2029, as a consequence of the fact that pipeline gas from 2030 is expected to consist of 100% bio-natural gas.

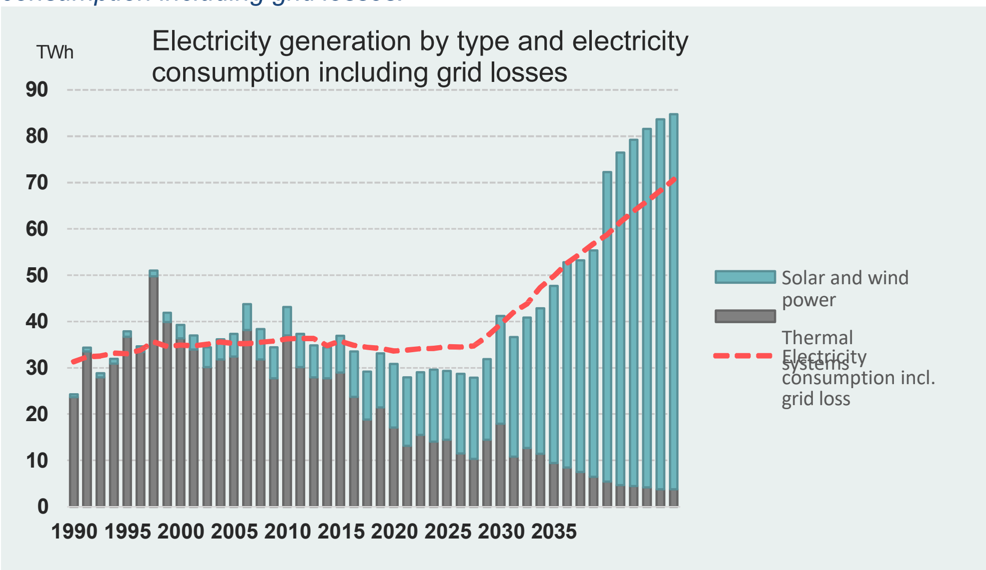
It can be noted that the increase in energy consumption from 2021 to 2022 in KF23 is an overall consequence of an increase in the energy consumption of all energy forms, except natural gas. The development, including the increase in the modeled energy consumption of e.g. coal and oil in 2022, is particularly affected by changes in fuel prices. In terms of modeling techniques, this is because the increased fuel prices will raise the electricity price, which makes it advantageous for Danish electricity producers to increase thermal electricity production. It should be noted that 2022 is a model year and that the results may differ from the statistics.

In addition, a growing contribution to district heating production from heat pumps and waste heat from industries is expected to reduce the consumption of bioenergy, mainly wood biomass, in the period up to 2035. While electricity and district heating production have historically been closely linked through large-scale combined heat and power production, in the future the link will be due to the widespread use of electrically powered heat pumps in the district heating supply.

Focus on the electricity supply

The fundamental transformation of the Danish electricity and district heating sector involves a significant change in the production mix. Figure 4 illustrates the technological development in electricity supply to date and how it is expected to continue in the projection period. In 1990, 97% of domestic electricity generation was from thermal plants, most of which were coal-fired, and only 3% from solar and wind power plants. By 2020, the thermal share had fallen to 37% and by 2030, the thermal share in electricity generation is expected to be only 7%, mainly based on biomass with a limited contribution from fossil fuels.

Figure 4: Domestic electricity production by production type and electricity consumption including grid losses.



In most years of the projection period, the absolute growth in electricity production from renewable energy plants is expected to exceed the annual growth in domestic electricity consumption, with the exception of 2023 and 2028. While the exact annual phasing-in of the expansion is subject to considerable uncertainty, it is a clear expectation that the accumulated growth in renewable energy production over the projection period will exceed the corresponding accumulated growth in electricity consumption.

In addition, higher fuel prices, including in particular for natural gas, which is often a price-setting technology for spot prices in the electricity market, are expected to mean that in the short term in 2021 and 2022, Danish coal- and biomass-fired power plants will have achieved an improved competitive situation in the Northern European electricity market. In the years ahead, however, a decline in thermal production is expected from the high level in 2022, which more than offsets the RE expansion rate in the first years of the projection period. Overall, Denmark is thus expected, in the absence of new initiatives, to be a net importer of electricity from 2021 to 2029 with the exception of 2027, although this is associated with considerable uncertainty[3]. The strong expansion of RE production in 2030, primarily in the form of offshore wind, means that Denmark will be a net exporter from 2030 onwards.

Between 2023 and 2029, net imports of electricity fluctuate between 3% and 13% including net losses, with the highest imports expected in 2023. In 2027, there is a marginal electricity surplus and thus net exports. The short-term trajectory is primarily driven by the decline in thermal electricity generation from 2022 and 2023, along with an increase in electricity consumption and the fact that

[3] The projection also includes a small electricity export in 2022, but in practice there was a small import in 2022 based on preliminary calculations from Energinet.

From 2030 and up to 2035, on the other hand, the projection calculates an annual net export of 20-24% of electricity consumption, which is primarily driven by expectations of a strong expansion of offshore wind power in 2030, based on the agreement from the 2022 Finance Act and the phasing-in of Energiø Bornholm (see KF23 sectoral assumptions note on electricity and district heating - Offshore wind power). Although electricity consumption is expected to increase further after 2035, the production of primarily renewable energy increases roughly correspondingly, resulting in the share of net exports in the projection remaining roughly constant up to 2035.

However, the results above are subject to great uncertainties and are particularly dependent on the commissioning dates of future offshore wind farms and large onshore wind farms. In addition, the KF23 baseline does not include an expansion with an additional 4 GW *of* offshore wind as agreed under the *Climate Agreement on Green Power and Heat of*
25. June 2022 (DKMII), an expansion of the North Sea Energy Island (see further details in the KF23 sectoral prerequisite memorandum on electricity and district heating - Offshore wind), a full achievement of the quadrupling of production from onshore wind (see further details in the KF23 sectoral prerequisite memorandum on electricity and district heating - Onshore wind and solar cells, respectively). Onshore wind, Solar PV) or a full achievement of the 4-6 GW PtX target as stated in the *Agreement on the Development and Promotion of Hydrogen and Green Fuels of March 15, 2022* (see more details in the KF23 sector premise note on Production of oil, gas and RE fuels - PtX).

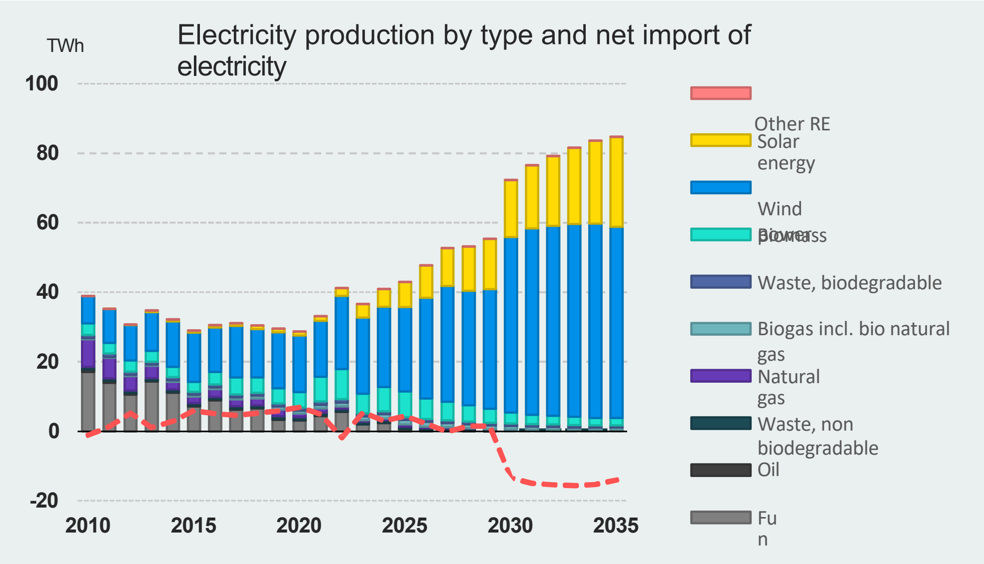
As a supplement to the KF23 baseline scenario, an alternative scenario has been prepared in section 3.2, where the North Sea Energy Island and the additional 4 GW of offshore wind from the *Climate Agreement on Green Power and Heat of June 25, 2022 are* included. This shows that the additional offshore wind production will significantly increase the export of RE-based electricity from Denmark and thus either have a positive climate effect in the European electricity system thanks to the displacement of fossil-based electricity production abroad, or open up opportunities for increased electricity consumption in Denmark, e.g. for the production of synthetic green fuels in Power-to-X (PtX) plants, or both.

The role of the electricity sector in the green transition

The projection shows that the electricity and district heating sector will only contribute marginally to Denmark's greenhouse gas emissions in 2030 and 2035. Electricity generation in Denmark in 2030 and 2035 will primarily be based on solar and wind energy, while the remaining thermal share of electricity generation will mainly be based on biomass, as shown in Figure 5.

From a climate perspective, the Danish electricity supply is therefore expected to become part of the solution rather than part of the problem, as RE-based electricity can supply other sectors and thus contribute to the reduction of their respective emissions, via either a direct electrification of society or an indirect electrification through PtX. However, the prerequisite for this is that the increasing electricity consumption is accompanied by continued RE expansion.

Figure 5: Electricity production by type and net import of electricity, 2010-2035.



Focus on district heating supply

The production of district heating has also undergone major changes, primarily away from fossil fuels such as coal and natural gas towards a greater use of biomass.

The reorganization of the framework conditions for investments in district heating production capacity (KF23 Sector Assumptions Memorandum Electricity and District Heating - Thermal Capacity) and the expectation of future electricity price levels result in a large expansion of heat pumps in the projection. The installed heat capacity of heat pumps is expected to increase from 382 MW in 2021 to 3,217 MW in 2030 and 3,600 MW in 2035, and heat pumps are expected to cover almost 39% of district heating consumption in 2030 and just over 40% of district heating consumption in 2035. 3.217 MW of heat capacity from the heat pumps requires an electricity capacity of approx. 860 MW, as heat pumps have a so-called "COP factor" (efficiency) that can vary between 300% and 500% depending on the heat source and plant size (Danish Energy Agency, 2020).

2.2 Selected elements in the sector

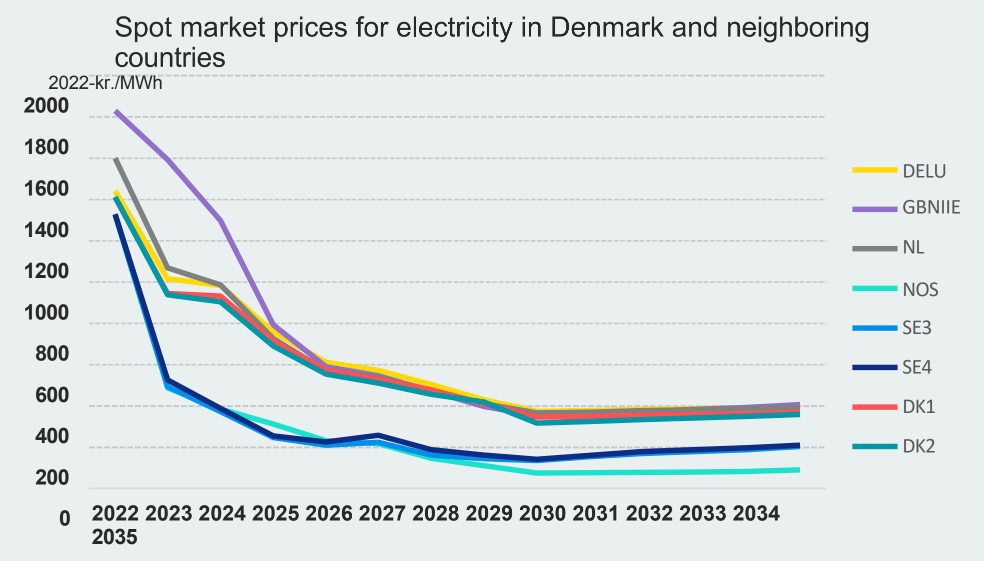
This section presents detailed information and explanations on the development of the electricity and district heating sector, including the expected composition of electricity and district heating production towards 2030 and 2035, respectively.

Electricity price development

Denmark is part of a common European electricity system and exchanges electricity with the countries Denmark is connected to via interconnectors. The composition of

electricity production capacity in Denmark's neighboring countries is expected to develop towards a greater expansion of RE production capacity and the phasing out of conventional production units. At the same time, the European grid is also expected to be reinforced with more and stronger electricity connections between the countries (cf. KF23 Sector Assumptions Memorandum for Electricity and District Heating, Chapter 3: Foreign electricity production capacities, etc.) Fuel prices are expected to be high in 2022-2023, which will lead to high electricity prices for all market areas in the short term.
The expansion of renewables is subsequently expected to contribute to falling electricity prices towards 2030 and 2035.

Figure 6: Spot market prices for electricity in Denmark and Denmark's neighboring countries.



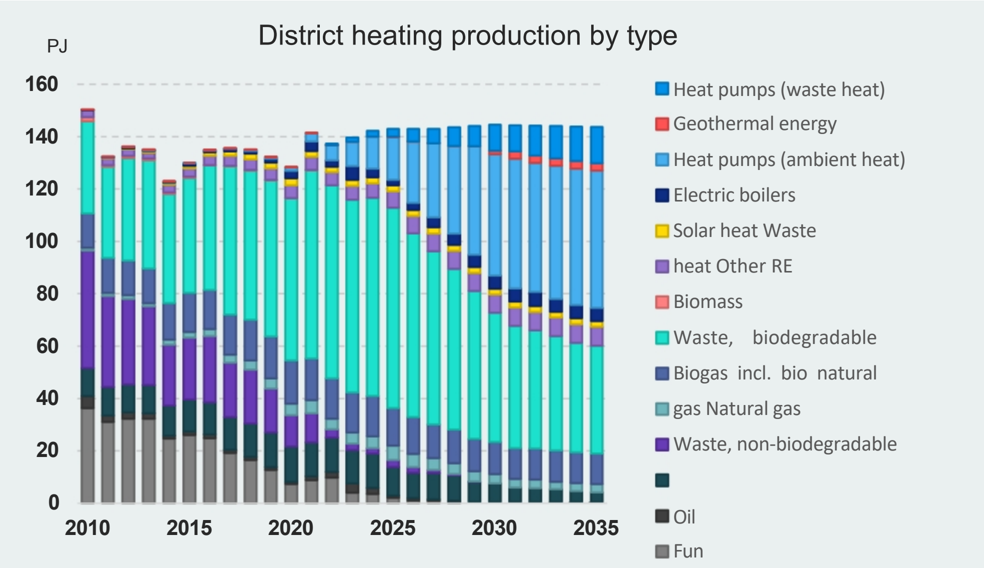
Note: Prices in all years are model results and are calculated as an arithmetic average of hourly prices. The actual spot prices for 2022 were 10-20% higher. In connection with the Danish Energy Agency's use of electricity price results, forward prices for 2023-2024 are used.
Forward prices for 2023 and 2024 in 2022 DKK/MWh are 945 and 932 for DK1 and 940 and 905 for DK2, respectively. Prices are updated in March 2023. DELU: Germany-Luxembourg, FI: Finland, GBNIIE: United Kingdom, NL: Netherlands, NOS: South-Norway, SE3: South-Central Sweden, SE4: South-Sweden.

It should be noted that the electricity price development in Figure 6 is associated with great uncertainty and is particularly dependent on the applied scenario for capacity development abroad.
The electricity price is also sensitive to changes in fuel prices and the price of CO_2 allowances.

The composition of district heating production

Falling electricity prices from 2023 will, among other things, affect the future development of the Danish district heating sector. The distribution of district heating production in the period 2010 - 2035 can be seen in Figure 7. Lower electricity prices contribute to making investments in large heat pumps more profitable. At the same time, lower electricity prices mean a deterioration in the operating economy of CHP plants, which in the projection results in a gradual reduction of natural gas-based CHP capacity in particular.

Figure 7: District heating production by type, 2010-2035.



Biomass has played an increasing role in district heating production over the last decade. In central CHP areas, new biomass CHP capacity has replaced coal-based district heating production, and in smaller district heating areas, new biomass-based heating plants have partially replaced natural gas as a fuel for district heating production.

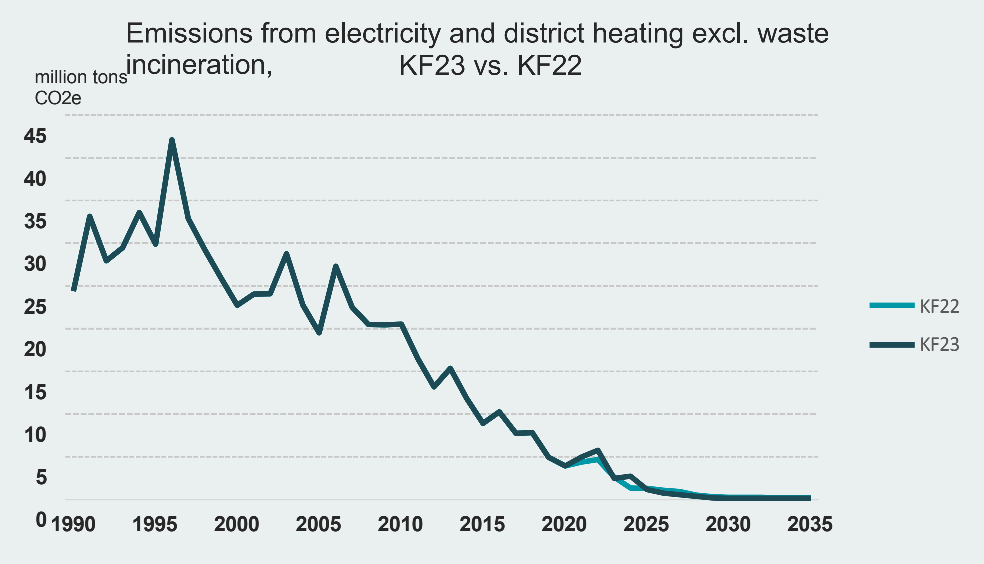
District heating production from biomass accounted for 48% of total production in 2020 and is expected to peak in 2022 at 54%. The biomass share in district heating is then expected to fall to 34% in 2030 and 29% in 2035, mainly due to increased production from heat pumps. The impact of biomass consumption for electricity and district heating production on the sector's emissions is presented in the appendix to this report.

3. Qualification of the KF23 process

3.1 Comparison with sector emissions in KF22

Figure 8 below compares the sector's emissions with last year's projection. Emissions from the electricity and district heating sector are higher in CC23 from 2021 to 2024 than in CC22 with the exception of 2023. For 2021, this is due to updated statistics, while for 2021-2024 (with the exception of 2023) it is due to an increasing consumption of fossil fuels in these years in CC23 compared to CC22.

Figure 8: Development in emissions from electricity and district heating excluding waste incineration for KF23 vs. KF22



Effect of rising fuel prices in the short term in the electricity and district heating sector

A significant increase in fossil fuel prices in 2022 to 2024 (see KF23 Sector assumptions note Prices and growth) will result in a higher share of coal for electricity and district heating production in these years than seen in KF22. This is because the increased fuel prices will raise the electricity price, which makes it advantageous to increase electricity production on coal. The effect of the higher consumption of coal in 2022 and 2024 will be seen in the results for emissions in the respective years from the electricity and district heating sector in CC23. However, the development in the electricity price as well as modelling assumptions on the operation of thermal power plants cause additional system dynamics that result in a slightly lower consumption of coal in 2023 compared to CC22. This contributes to lower emissions in the sector in this year compared to CC22.
The outcome is uncertain and depends, among other things, on the short-term development of fuel prices as well as electricity production and demand in the European electricity market.

3.2 Uncertainty and sensitivity calculations

The projection of the electricity and district heating sector is subject to great uncertainty. The main sources of this uncertainty are:

- Development in fuel prices and CO2 allowance price
- Power consumption development, especially power consumption for data centers and PtX
- Domestic expansion with open-door offshore wind, onshore wind and solar PV
- Development in the composition of electricity generation capacities abroad

In addition, there are uncertainties about future investments in district heating production capacities, including the price development of large heat pumps and the influence of local conditions on investment decisions. Please refer to the respective KF23 assumption notes (Prices and growth, Production of oil, gas and renewable fuels and Electricity and district heating) for a more detailed description of the specific uncertainties.

As a supplement to the KF23 basic course, an alternative course has been developed where the North Sea Energy Island and 4 GW offshore wind *from* the *Climate Agreement on green power and heat from June 25, 2022* is included. Other assumptions are as in the baseline scenario. In addition, the effects in the electricity and district heating sector are examined for two additional alternative scenarios with different capacity projections for waste. These scenarios are also examined in sector memo 9A Waste Incineration.
In order to uncover the uncertainties associated with technological developments in the electricity and district heating sector, behavioral changes and external factors, two partial sensitivity analyses are also presented that attempt to uncover the uncertainties. "Partial" means that a change is made in relation to the KF23 baseline "all other things being equal" without taking into account derived effects in the overall system, and that the results from the sensitivities cannot be directly aggregated. Furthermore, two cross-cutting sensitivities are presented, where derived effects in the overall system are taken into account.

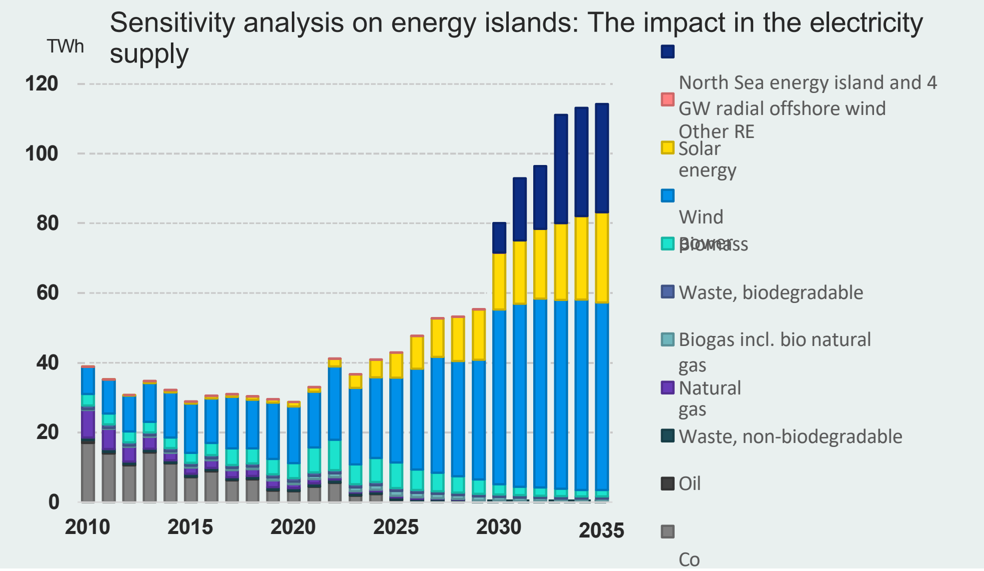
Partial alternative supply-side path with additional offshore wind
As described in the memorandum on electricity and district heating, the North Sea Energy Island and 4 GW of additional offshore wind power are not included in the KF23 baseline scenario. The system and climate consequences of the commissioning of these projects for the Danish electricity and district heating sector are therefore examined here with a partial alternative calculation, where the 4 GW is assumed to be commissioned in 2030 and where the Energy Island North Sea is assumed to be realized and connected to the grid in 2033.

The 4 GW offshore wind in connection with the Climate Agreement for Green Power and Heat of 2022 is assumed in this calculation to be distributed as 1 GW at Kattegat II, 1 GW at Kriegers Flak II and 2 GW located in the North Sea.
The North Sea Energy Island is expected to have an electricity capacity of 3 GW connected to Western Denmark and Belgium[4]. A final investment decision between the TSOs (the Danish TSO, Energinet, and the Belgian TSO, Elia, respectively) on the connection to the North Sea Energy Island has not been made at this time, so the configurations of the international connections may change until the final investment decision is made. The alternative calculation only aims to describe the system and climate impact of the additional offshore wind in a Danish context, which is not estimated to vary significantly with a change in the countries to which the island is connected, as long as the generation capacity and the capacity of the electricity transmission links are kept constant.

[4] The 2022 Finance Act includes a target of a total capacity of 10 GW as soon as possible, with 2040 as the target point, while ensuring the necessary interconnections.

Assuming that Danish electricity consumption remains constant as in the KF23 baseline, the additional 4 GW of offshore wind and the North Sea Energy Island are expected to increase net electricity exports by 5.2 TWh in 2030 and 24.2 TWh in 2035 compared to KF23. KF23.

Figure 9: Sensitivity analysis on energy islands: Electricity production by type incl. energy islands and Danish electricity consumption incl. grid losses.



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The alternative calculation implies a significant increase in the renewable energy share in electricity consumption (RES-E5) to 131% in 2030, which is an increase of 14 percentage points compared to KF23. In 2035, RES-E increases to 162% compared to 118% in the baseline scenario. A RE share in electricity consumption higher than 100% means that Denmark is expected to have a surplus of green electricity that can be exported or contribute to reducing greenhouse gas emissions from other sectors through direct or indirect electrification. Impact assessments of new offshore wind projects do not include these possible derived CO2 displacement effects.

The alternative calculation also shows that the additional offshore wind in isolation does not have a significant impact on Danish greenhouse gas emissions, as the direct effect is
- 0.02 million tons CO_{2e} in both 2030 and 2035 compared to compared to the baseline. The reason for the small effect on emissions is the already high share of RE-based electricity in Denmark, which has displaced the majority of fossil electricity production. Higher electricity exports are possible due to new electricity transmission connections from Denmark to abroad via the energy islands. However, the energy islands will have a greater direct climate impact in the European electricity system, as the expected large Danish electricity export displaces fossil-based electricity production abroad.

[5] RES-E for the KF23 foundation course is presented in sector memo 11B.

Partial alternative supply-side scenario with less offshore wind development
To illustrate the effect of less offshore wind capacity in the Danish electricity system, an alternative scenario is examined in which the Energy Island Bornholm is not included. Energy island
Bornholm is included in the basic scenario with 3 GW from 2030. In connection with the construction of Energiø Bornholm, two new electricity connections to and from Energiø Bornholm will be established, connected to eastern Denmark and Germany, respectively. In this alternative scenario, the two interconnectors will not be included. The alternative scenario does not investigate whether the removal of Energiø Bornholm could affect the profitability of other offshore wind farms, but only the climate impact of less offshore wind in the electricity system.

The calculation with the alternative scenario does not show significant differences in greenhouse gas emissions. However, there is a decrease in the RE share in electricity consumption (RES-E). In 2030 and 2035, the RE share is 104% and 102%, respectively, compared to 117% and 118% in the KF23 baseline scenario. If Energiø Bornholm is not realized, there will, all else being equal, be a small surplus of green electricity in Denmark, which can either be exported abroad or used for direct or indirect electrification of other sectors.

Partial alternative paths for waste capacity adaptation
In KF23 sector memo 9A Waste Incineration, two alternative scenarios are described, one of which does not adapt the nominal, environmentally approved capacity of waste incineration plants as a result of competitive tendering. The other scenario assumes that the Climate Plan's objective of adapting waste incineration capacity to Danish volumes is met. In sector memorandum 9A, the effect of the alternative scenarios is only assessed in relation to the waste incineration sector's greenhouse gas emissions. The alternative scenario without adaptation of capacity leads to increasing emissions compared to the KF23 baseline scenario. KF23 baseline scenario due to increased utilization of the plants, whereas the scenario with full adaptation in relation to the KF23 baseline scenario.
The climate plan's targets lead to a deviating reduction path of emissions compared to the baseline. with a slight increase in emissions in 2025, but more strongly reduced emissions in 2030 compared to the baseline. KF23 baseline.

As a change in the capacity adjustment for waste incineration will lead to additional effects in the electricity and district heating sector, some of the other system effects seen in the two alternative scenarios are highlighted here.

The alternative scenario without capacity adjustment shows an increase in fuel consumption of waste for waste incineration plants compared to the KF23 baseline scenario. KF23 baseline scenario. This results in a reduction in fuel consumption of other fossil fuels, which results in a small change in total greenhouse gas emissions from the electricity and district heating sector, excluding waste, compared to the KF23 baseline scenario. KF23 baseline. In 2025 there is a decrease in greenhouse gas emissions of around 0.02 million tons $_{CO2e}$ and in 2030 and 2035 the change is close to 0.00 million tons CO_{2e}. In addition, there is a larger decrease in district heating production from both heat pumps and electric boilers, as more heat production comes from waste incineration. The total district heating production from electric boilers and heat pumps falls by 3%, 25% and 30% in 2025, 2030 and 2035, respectively, compared to the KF23 baseline. KF23 baseline. The total district heat production for the baseline is presented in Table 2 in the Appendix.

The alternative scenario with full capacity adjustment does not show major changes in the fuel consumption of waste compared to the KF23 baseline scenario. KF23 basic scenario. The fuel consumption of waste in 2025 is on a par with the scenario without capacity adjustment, in 2030 it is lower than the KF23 baseline and in 2035 it is higher. The change in greenhouse gas emissions in 2025 is a decrease of 0.02 million tons CO2e and in 2030 and 2035 it is close to 0.00 million tons $_{CO2e}$. The fuel mix does not change significantly compared to the KF23 baseline. KF23 baseline.

Partial sensitivities

Weather fluctuations

Historically, Danish electricity production has fluctuated greatly depending on conditions in the Nordic electricity market. In popular terms, the Danish fossil-fired condensing plants were an "energy reserve" for the Nordic region, which was activated in years with declining precipitation and thus less hydropower production. With the phasing out of coal-fired plants, this is a thing of the past, but varying wind conditions mean that wind power production can vary significantly from year to year, typically +/- 15%.

The climate projection is based on normal years, i.e. the projection does not take into account fluctuating wind conditions and precipitation in the future. To illustrate the impact of varying weather conditions on the electricity and district heating sector's emissions, two sensitivity calculations have been made. One assumes that weather conditions are favorable for electricity production from both wind and hydropower plants (+15% compared to normal year production), while the other sensitivity calculation assumes a simultaneous reduction in electricity production from wind and hydropower plants (-15% compared to normal year production)[6]. The magnitude of changes is determined based on statistical data for Denmark and the other Nordic countries.

The sensitivity calculation shows that fluctuations in precipitation and wind can lead to a maximum fluctuation in the sector's emissions in the order of -0.1 million tons CO2e to
+0.1 million tons $_{CO2e}$ in 2030. The sector's emissions are therefore expected to be less affected by weather fluctuations in line with the transition to renewable energy. In comparison, weather fluctuations in historical years have meant a fluctuation of +/- 5 million tons $_{CO2e}$.

However, weather fluctuations will still have a significant impact on other aspects of the energy system, including electricity imports/exports, electricity prices on the spot market and the use of biomass.

[6] The probability of the coincidence of a wet year with good wind conditions and a dry year with poor wind conditions has not been studied. The coincidence is assumed to investigate the most extreme variations in the electricity and district heating system.

Electricity consumption in connection with electrolysis

The electricity consumption for electrolysis in KF23 is based on an assumption of a consumption corresponding to 5000 full load hours for the total installed capacity[7]. To illustrate a higher electricity consumption, this assumption is adjusted upwards to 8000 full load hours, corresponding to the electrolysis plants being in operation for most of the year. This corresponds to an increase in electricity consumption of 1.8 TWh in 2030 and 3.3 TWh in 2035. The sensitivity calculation shows that this results in no increase in emissions in 2030 and an increase of 0.01 million tons CO_2e in 2035.

3.3 Planned development going forward

Please refer to the assumptions material for the methodological developments planned for future climate status and projections.

[7] Described in the Sector Assumptions memo on electricity and district heating.

4. Sources

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5. Attachments

Appendix 5.1 Biogenic energy-related CO2 emissions from the sector *The climate projection's calculation of the sectors' emissions follows the UN's calculation rules, as the emissions calculation in relation to the 70% target according to the Climate Act must follow these. 70% target according to the Climate Act must follow these. CO2 emissions from the consumption of biomass are included in the LULUCF sector in the country where the biomass is harvested. When burning Danish and imported biomass and biofuels for energy purposes, the resulting biogenic CO2 emissions are therefore not included in order to avoid double counting (cf. KF23 sector assumption memo Principles and policies - Emission inventory). However, according to UN regulations, CO2 emissions from the consumption of biomass for energy must be calculated and reported under a so-called "memo item". This appendix shows the total biogenic energy-related CO2 emissions associated with the combustion of biomass and biofuels.*

Figure 10 illustrates the development of the electricity and district heating sector's emissions according to the UN reporting methodology. To show the extent of biogenic emissions from the electricity and district heating sector, this is reproduced below together with a new curve showing the sector's emissions including biogenic CO2 emissions.

If the biogenic part of the sector's emissions is included, the electricity and district heating sector (excluding waste) is expected to emit 8.0 million tons CO2e in 2030, which corresponds to a 67% reduction compared to 1990 levels. In 2030, biogenic emissions are expected to account for 98% of the electricity and district heating sector's total emissions (excluding waste), and they are expected to come predominantly from biomass burning for district heating production (including especially wood biomass).

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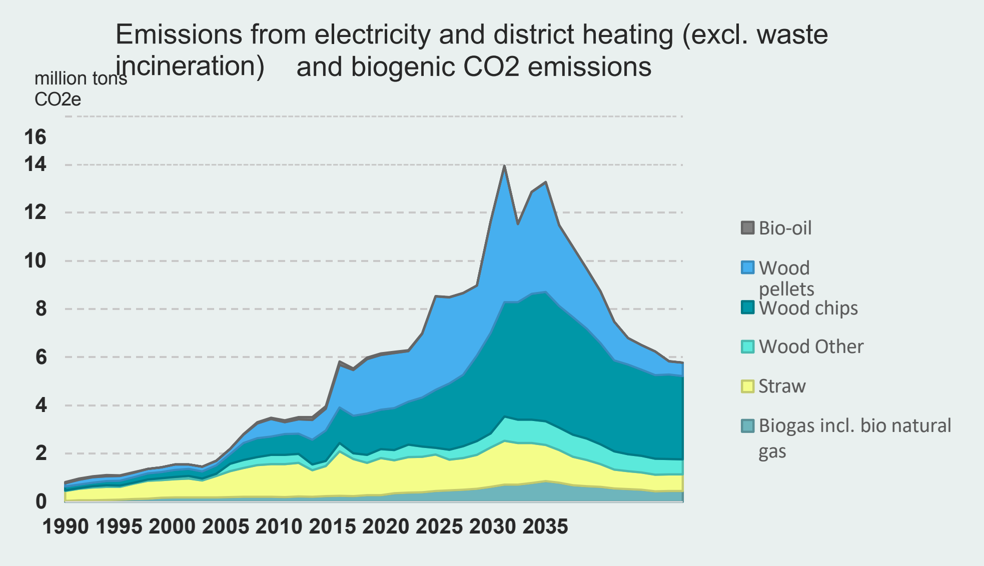
Figure 10: Biogenic energy-related CO2 emissions from the electricity and district heating sector (excluding waste incineration).



Appendix 5.2 Indicators from the sector

In the Climate Action Plan 2020, a number of indicators were established that can help assess the progress of the transition of the individual sectors in the future. This appendix presents data for the indicators relevant to the electricity and district heating sector.

In a broader perspective, it is interesting to follow whether it is biomass-fired thermal plants, wind power or solar cells, or waste heat, solar thermal or heat pumps that take over the production of electricity and district heating. The new supply sources and technologies that replace fossil-based production have very different characteristics, e.g. how large areas they require or how flexible they are, and this gives them different strengths and weaknesses in the overall green transition of the electricity and district heating sector.

In Table 1 and Table 2 below, the distribution is given in five selected base years, where 1994 is the first year for which data in this form is available, 2020 is the latest statistical year (Danish Energy Agency, 2022), and 2035 is the last projection year.

Table 1: Electricity production in 1994, 2010, 2020, 2030 and 2035 by fuel/type.

Electricity production by fuel/type	**1994 TWh**	**1994 Pct.**	**2010 TWh**	**2010 Pct.**	**2020 TWh**	**2020 Pct.**	**2030 TWh**	**2030 Pct.**	**2035 TWh**	**2035 Pct.**
Fossil fuels	38,2	95,3	25,7	66,1	4,3	15,0	0,1	0,1	0,1	0,1
Garbage	0,5	1,2	1,7	4,3	1,7	6,0	1,1	1,5	0,9	1,0
Biomass[8]	0,3	0,7	3,7	9,5	5,2	18,0	4,3	5,9	2,9	3,4
Wind power	1,1	2,7	7,8	20,1	16,3	56,9	50,5	69,9	55,0	65,0
Solar energy[9]	0,0	0,0	0.0	0,1	1,2	4,1	16,3	22,6	25,9	30,6
In total	40,1	100	38,9	100	28,7	100	72,3	100	84,7	100

As shown in Table 1, there has been a sharp reduction in the share of electricity generation from fossil fuels since 2010. Production that has primarily been replaced by production from wind power, biomass and solar.

Table 2: District heating production in 1994, 2010, 2020, 2030 and 2035 by fuel/type.

District heat production by fuel/type	**1994 PJ**	**1994 Pct.**	**2010 PJ**	**2010 Pct.**	**2020 PJ**	**2020 Pct.**	**2030 PJ**	**2030 Pct.**	**2035 PJ**	**2035 Pct.**
Fossil fuels	87,5	77,4	85,5	57,1	20,1	15,7	2,2	1,5	0,6	1,6
Garbage	13,5	11,9	23,6	15,7	30,0	23,4	19,5	13,5	15,4	10,7
Biomass[10]	9,2	8,1	38,1	25,3	66,6	52,0	51,0	35,3	42,5	29,6
Excess heat	2,8	2,5	2,5	1,7	4,6	3,6	6,9	4,8	7,1	4,9
Solar heating	0	0	0,1	0,1	2,6	2,0	2,2	1,5	2,3	1,6
Boilers and heat pumps[11]	0,1	0,1	1,2	0,1	4,2	3,3	62,7	43,4	74,1	51,6
In total	113,1	100	151,0	100	128,1	100	144,5	100	143,6	100

An almost similar reduction in the share covered by fossil-based production can, as shown in Table 2, be seen in district heating production, but here biomass has played the most important role, followed by waste, waste heat and solar. By 2035, heat pumps are expected to play a very prominent role in district heating production.

Appendix 5.3 Sector emissions by fuels

The sector's greenhouse gas emissions have historically been driven by coal consumption for electricity and district heating production, as shown in Figure 10. The development towards 2030 and 2035 is mainly due to the phasing out of coal-fired CHP at central plants and a gradual but sustained displacement of natural gas consumption since 2010.

[8] Biomass is incl. biogas
[9] Solar energy is incl. hydro
[10] Biomass is incl. biogas
[11] Boilers and heat pumps include geothermal

Figure 11: Emissions from the electricity and district heating sector (excl. waste incineration) by fuel.