Appendix C

Country Report Denmark

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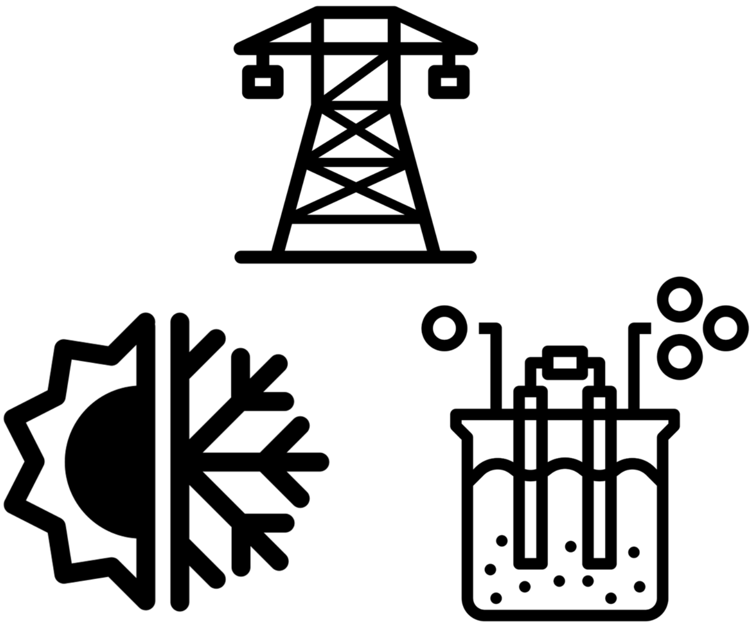

IEA DHC ANNEX TS3: HYBRID ENERGY NETWORKS

APPENDIX C
COUNTRY REPORT DENMARK

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CONTENT

1 INTRODUCTION

This Appendix is part of the IEA DHC Annex TS3 guidebook. The full guidebook is available at https://www.iea-dhc.org/the-research/annexes/2017-2021-annex-ts3

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2 THE OVERALL PICTURE

Denmark aspires to transition to a low-emission society and an energy system independent of fossil fuels by 2050. Presently, the share of renewable energy in total primary energy consumption is 37%, indicating that fossil fuels still contribute substantially to the Danish energy consumption. For the electricity consumption 61% is supplied by renewable energy, mainly due to a large wind power production, supplying 46% of the total electricity demand.

Denmark has a well-established tradition for integrating energy sectors, for example the gas and heat sectors - a practice that has resulted in an efficient energy system. The extensive use of district heating has allowed for an efficient use of combined heat and power plants, supplying the Danish district heating sector with excess heat produced alongside electricity.

Going forward, storage and integration of variable renewable energy will be important due to the increasing share of variable renewable energy production from primarily wind power. Such storage and integration measures include an increased electrification of the heat sector by increasing deployment of electric heat pumps and electric boilers alongside additional heat storage capacity, electricity for transport purposes or power-to-gas products, or electrical storage based on either Nordic hydropower or short-term battery storage. This process is underway in Denmark, and in recent years many Danish district heating areas have installed electric heat pumps (PlanEnergi, 2020).

1. **Early adopter of wind power. Currently, 46% of electricity production coming from wind power.** Wind power has been a well-established part of the Danish energy system since the 1970’s. Traditionally, wind power was mainly deployed onshore, but is now increasingly offshore.

2. **Extensive use of district heating provides large potential for integration of heat and electricity sectors.** The Danish tradition for district heating sector provides balancing of the fluctuations caused by high share of variable renewable energy production from wind power, and cheap storage of energy through the use

3. **Market based interconnection to neighbouring countries.** The Danish energy system is interconnected with neighbouring countries such as Norway, Sweden, Germany, Netherlands, which enables exchange of electricity and provides mutual system flexibility. A new connection to England is being established.

4	**Historic high degree of flexibility in the energy system from CHP plants.** Historically the district heating sector has been supplied to a large extent by highly flexible CHP plants. It is uncertain what role CHP will have in the future due to increased utilisation of excess heat from industries, electrofuel production, and
5	**Ambitious 2030 and 2050 renewable energy targets.** The Danish government and political parties have agreed on a targeted 70% reduction of CO_2 emission by 2030, and 100% reduction in 2050. Political agreements are concurrently being developed with initiatives aimed at achieving these goals.

KEY STATISTICS

In the 1970's the Danish energy system was highly dependent on oil, but after several oil crises a desire to diversify energy resources arose (Lund, 2010). This at first resulted in a transition to coal-based power plants and combined heat and power (CHP) plants, and later to natural gas and renewable energy. The oil crises also put focus on improving the energy efficiency of the energy system, both in the transformation and at the end-user. This progression is illustrated in Figure 1, resulting in an energy system that is more diverse than the energy system of the 1970's.

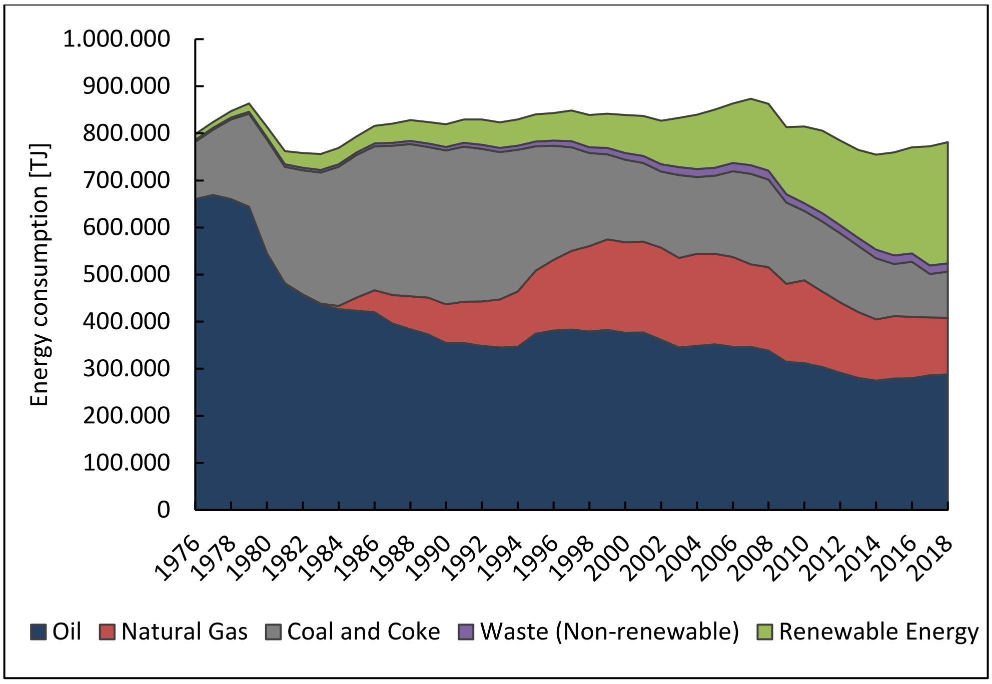

Figure 1: Gross energy consumption (adjusted to climate fluctuations and net electricity export) (Danish Energy Agency, 2019).

The renewable energy production has increased to 37% of the final energy consumption (in 2018). This has mainly been driven by an increased use of biomass in fuel boilers and CHP plants in district heating, and conversion of large coal-fired extraction plants central power plants and CHP plants to biomass. Wind power is the second-largest contributor to renewable energy, while other resources such as solar, geothermal, etc. only contribute to a limited extent (Figure 2).

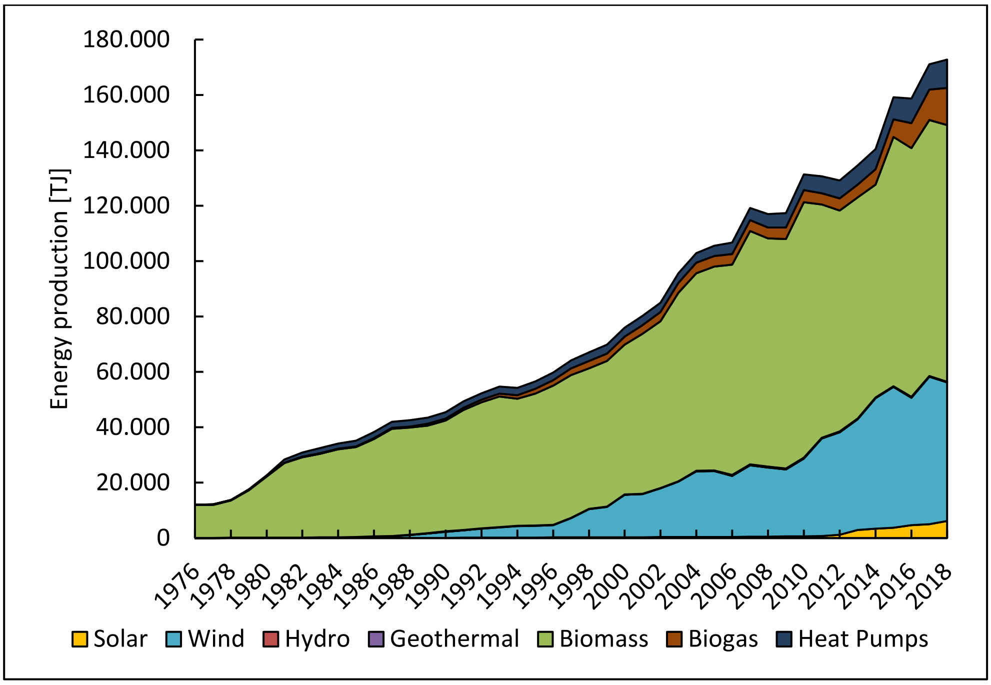

Figure 2: Production of renewable energy (observed production) (Danish Energy Agency, 2019).

Wind power is likely to remain an important source of renewable energy in Denmark, because of the potential for offshore wind power expansion in the North Sea and the Baltic Sea. This is to be supplemented by other renewables, such as biomass, photovoltaics, solar thermal panels, and geothermal energy. Because there is little to no potential for hydropower in Denmark, and a strong historic and present public opposition to nuclear power, these options are generally not expected to play a role in the transition towards lower CO_2-emissions from the energy system. Chapter 4 will go into further details on the future development of the Danish energy system.

The development of CO_2-emissions can be seen in Figure 3. Figure 3 includes both observed and adjusted CO_2 emissions. Observed CO_2-emissions are the emissions that actually occurred in a year, while the adjusted CO_2-emissions are emissions adjusted to the annual temperature differences and foreign electricity trade. Thus, the adjusted CO_2-emissions are mainly used to illustrate a general trend independent of fluctuations in temperature and electricity exchange. Since 1990 the CO_2-emissions have decreased by 38%, mainly due to a shift in fuel consumption from oil and coal to natural gas, and due to the increasing use of renewable energy.

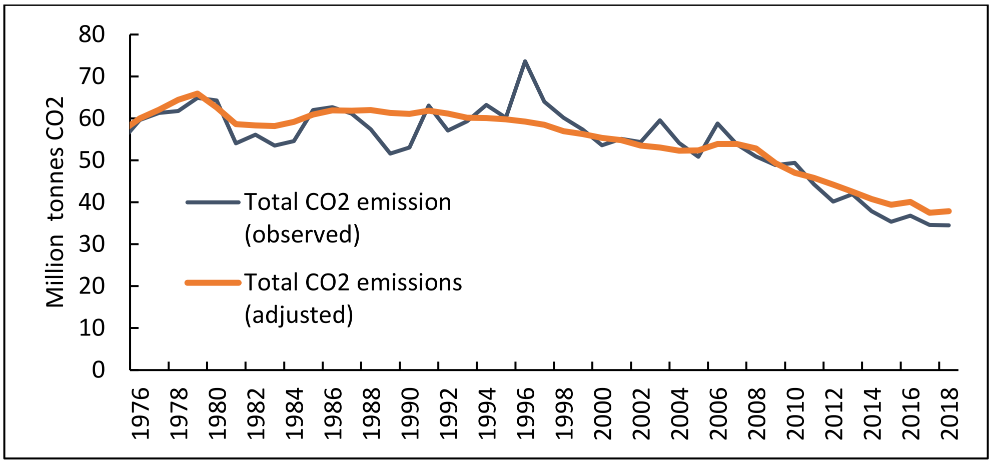

Figure 3: Total CO_2 emissions (Danish Energy Agency, 2019).

POLICY AND STRATEGY

Being part of the European Union (EU), Denmark is obligated to contribute to realizing the common European 2030 40% greenhouse gas emission reduction target. However, the Danish government has established a more ambitious 2030 target of 70% reduction, along with a 2050 target of 100% emission reduction, in line with the goal of a climate-neutral EU in 2050 (European Commision, 2018). This chapter elaborates on the purpose and definition of these targets, and the past and present energy policies related to the fulfilment of these targets. Finally, the chapter introduces central business models in the context of the Danish energy system and the current transition.

A.1.1 POLITICAL GOALS AND AGREEMENTS

In December 2019, the Danish Parliament agreed on a 70% GHG emission reduction goal for 2030, implemented as a binding climate act. The target is to be realized while taking into account e.g. cost efficiency and measures that result in in-country CO_2-reductions (Ministry of Climate, Energy and Utilities, 2021)

The climate law introducing the 70% emission reduction target does not outline the measures and initiatives needed to reach this target. Instead, it only presents responsible authorities and designates organisations overseeing and advising the government. Thus, currently few concrete measures on how to reach this target have been suggested by the Government, some of the most prominent ones are:

- **Energy islands:** Establish two energy islands to facilitate a lower cost implementation of offshore wind power. Long-term these islands are also expected to enable storage and conversion of energy, e.g. through P2X technologies.
- **Investments in future technologies – P2X and carbon capture:** To support the development of new technologies for P2X and carbon capture.
- **Industrial energy efficiency, tax reforms, and more:** Funding is allocated for industries implementing energy savings, electrification, and increased use of biogas. Several tax reforms are introduced, including a reduced tax for excess heat utilisation, and a reduced tax on electricity used for heating. Other initiatives include some support for private households looking to replace their oil or natural gas boiler, and some funds supporting the build-up of electric vehicle charging infrastructure.

In 2012, a 100% renewable energy target for 2050 was first introduced, and since then this agreement has been confirmed in several ensuing energy agreements. Most recently this was ratified in 2018 through an Energy Agreement supported by all parties of the Danish parliament. While establishing a foundation and timeline for such a transition through a political agreement is commendable, as an isolated initiative it is insufficient without being accompanied by technical, institutional, and regulatory changes.

A.1.2 ENERGY PLANNING AND POLICY

The story of the Danish energy system transition from the 1970s to 2020 is to a large extent also the story of a continuous political struggle and balancing of centralisation and decentralisation (Hvelplund F, 2020). Some established market actors have fought to maintain a centralised energy system approach, while NGO's and innovative industries have struggled to introduce a more decentralised approach where the integration of fluctuating renewable energy technologies is easier.

Throughout the 1980s and 1990's the Danish energy system was supplemented with more than 400 decentral natural gas-based CHP plants along with increased development of district heating areas, leading to an improved diversification of the energy system and a reduced reliance on oil (Lund, 2014). While not originally the intention of this decentralisation process and district heating expansion, it has proven to be very useful in the integration of fluctuation renewable energy. District heating remains an essential part of the Danish energy system, and still in 2020 more than 370 district heating areas exist with district heating supplying heating to more than 64% of all households in Denmark (Danish Energy Agency, 2019).

For the last 20 years, discussions on the balancing of centralised and decentralised energy system approaches have been apparent in discussions of future strategies on the development of the energy system. Historically, the Danish municipalities have had an important role in planning of the energy system, and in particular for the heat sector, including district heating. The municipalities are responsible for ensuring that only the most socioeconomically beneficial projects and heat supply plants are implemented. This means that before a district heating company is able to install a new production technology, e.g. an electric heat pump, the district heating company needs to prove that the project has a positive socio-economic impact and that it compares favourably to other potential alternatives. In addition to heat planning, municipalities are increasingly involving themselves in strategic energy planning in a broader sense (Krog, 2019) (Krog, 2019). Such planning includes development of energy scenarios and establishment of concrete renewable energy targets, often more ambitious than the national targets.

CURRENT ENERGY SYSTEM OF DENMARK

This chapter provides an overview of the primary energy production technologies and energy demands in Denmark, with an outlook towards how the future energy system is expected to develop and how technologies should be integrated across different sectors and energy grids. Scenarios for the future Danish energy system are described more in chapter 4.

As can be seen in Figure 5, the energy Danish energy consumption is fairly equally distributed across four sectors households, commercial and public services, agriculture and industry, and transport. A distribution of fuels was shown previously in Figure 1.

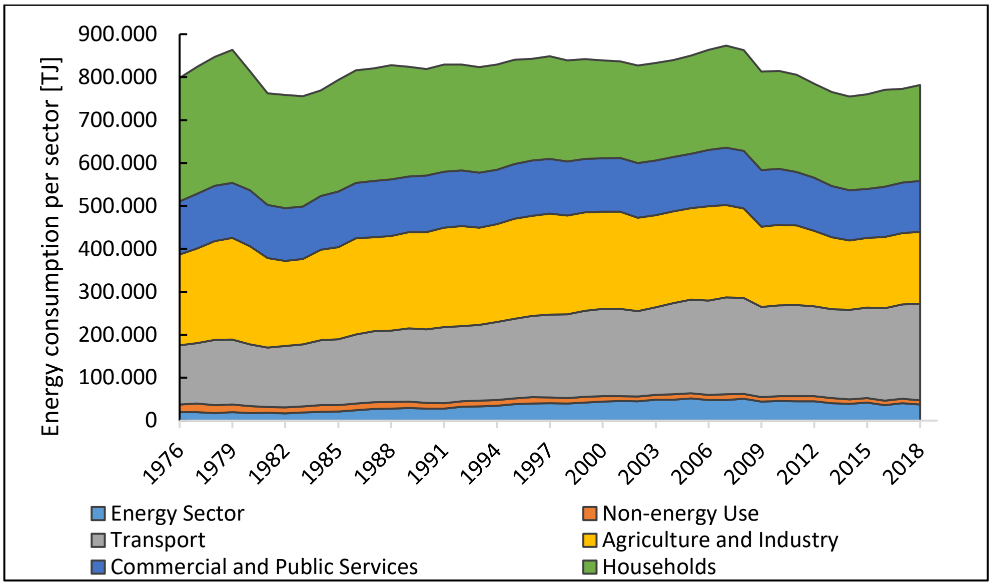

Figure 4: Energy consumption per sector (Danish Energy Agency, 2019).

A.1.3 PRODUCTION OF ELECTRICITY, DISTRICT HEATING AND DISTRICT COOLING

An overview of the Danish electricity production can be seen in Figure 7, illustrating that the electricity production is already primarily renewable. This is supplemented by some natural gas and coal-based production, mainly from large central CHP plants. Figure 5 illustrates what is included in the renewable electricity production – mainly wind power with some biomass-based electricity production. The biomass share has increased in recent years, and may continue to do so, as several coal-based power plants plan to convert to biomass. However, biomass is a limited resource and may be needed in sectors other than the electricity sector, e.g. for industry and transport energy demands (Korberg AD., 2020; Mortensen, 2020).

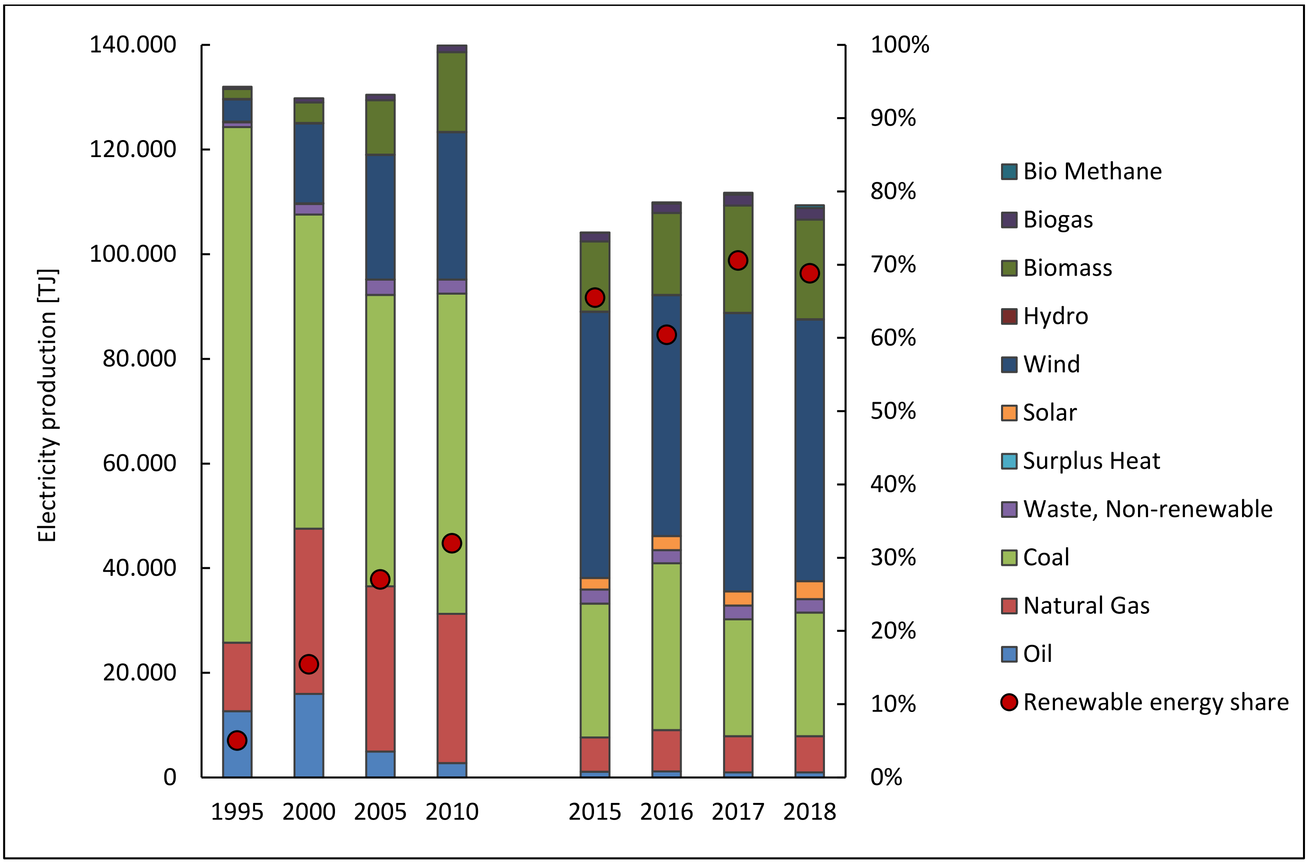

Figure 5: Total production of electricity by fuel (Danish Energy Agency, 2019)

In 2018 46% of the total electricity production comprised of electricity produced by wind turbines, while 35% was produced on large-scale CHP units, and 8% was produced on small-scale CHP units. The remaining 11% was supplied by a mix of autoproducers, which are producers whose primary role is not the production of energy, such as waste incineration CHP units.

The electricity system in Denmark is well-connected to neighbouring countries by electricity transmission lines. This enables export of renewable during hours of large Danish wind power production, and import during low production hours, e.g. from Norwegian hydropower reservoirs. In Figure 6 the total import and export from Denmark to neighbouring countries can be seen for the last five years, showing that generally Denmark is a net-importer of electricity.

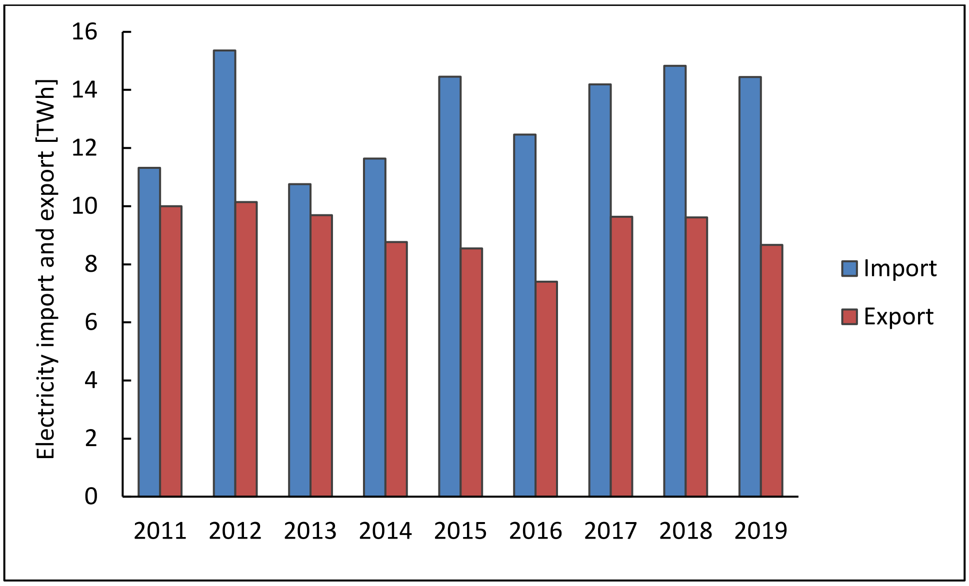

Figure 6: Import and export of electricity from Denmark (Energinet, 2020).

District heating has, as mentioned in Chapter 2, been important for the development of the Danish energy system, enabling integration of fluctuating renewable energy. This has resulted in a district heating sector where a majority of the energy is supplied from renewable sources as seen in Figure 7.

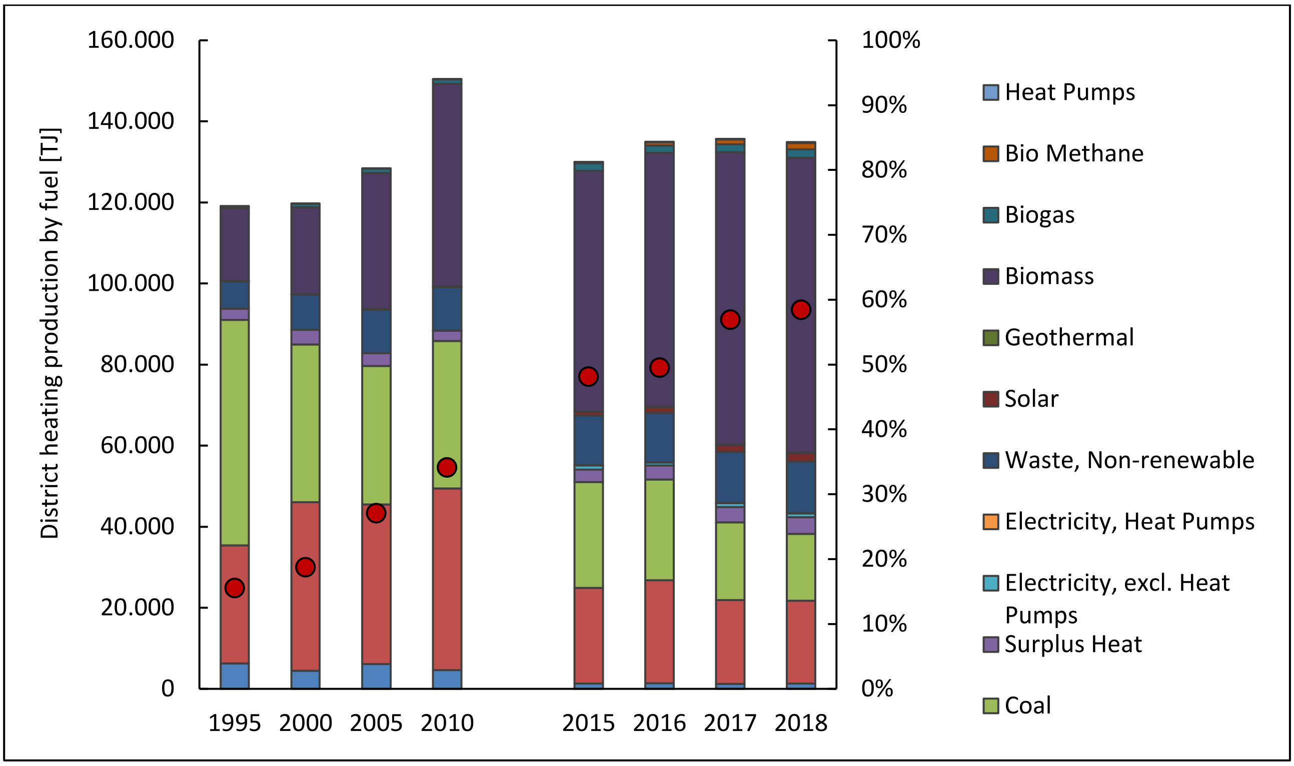

Figure 7: District heating production (Danish Energy Agency, 2019).

While the renewable energy share in district heating is relatively high, this is mainly due to an extensive use of biomass, supplying 92% of the renewable energy, with a large part being due to the refurbishment of large coal-fired CHP units to being biomass-fired instead. However, further expansion of this may not be possible as biomass may need to be prioritized elsewhere (Mathiesen, 2012), as also described in chapter 4; hence, other avenues must be explored to attain a 100% renewable district heating sector. In the future, an increased installation of electric heat pumps and electric boilers coupled with heat storage is expected, as shown in chapter 4.

Similarly, it is expected that district heating will continue the historic trend towards lower supply and return temperatures in the grid. The current temperature levels are often defined as 3rd generation district heating, and a transition to low-temperature 4th generation district heating systems (Lund, 2018; Lund H., 2018) could present opportunities for increased utilisation of e.g. heat pumps and low-temperature excess heat. 4th generation district heating entails a shift away from a supply- and production centred approach, and instead emphasises the importance of energy conservation, lowering supply/return temperatures and grid losses, and increasing integration of low-temperature heat sources. This transition to 4th generation district heating would support increased electrification of the district heating sector through a combination of electric heat pumps, heat storage, and electric boilers for peak loads. Furthermore, data centres could prove to have an important double-role in the Danish energy system as both electricity consumers and suppliers of excess heat for district heating (Petrović, 2020).

A.1.4 ENERGY CONSUMPTION IN HOUSEHOLDS

In Denmark, the energy consumption in households is presently primarily used for heating, followed by electricity (Danish Energy Agency, 2019). The distribution of fuel types for heating relative to electricity consumption can be seen in Figure 8.

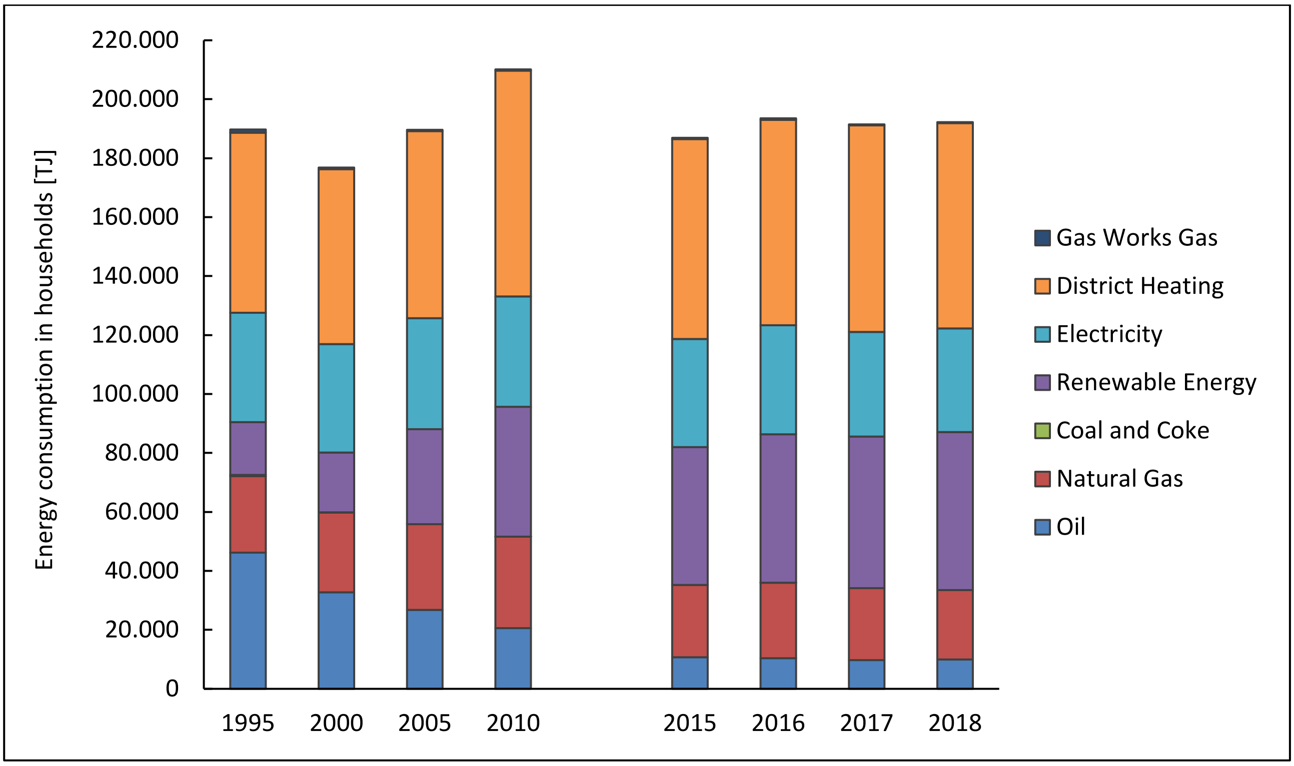

Figure 8: Energy consumption in households (Danish Energy Agency, 2019).

There are several observations to note from Figure 8. The significant contribution share of heat supply from district heating stands out, of which a detailed breakdown was included in the previous Figure 7. Similarly, to what was seen for district heating, renewable energy is responsible for a large share of the individual heat consumption. However, once again, this is largely due to an extensive use of biomass, mainly firewood, wood pellets, and straw. To a lesser extent, renewable energy in Figure 8 also includes solar energy and heat pumps. Fossil fuels in the form of natural gas and oil used in individual boilers are also still present in the Danish households. This presents an obvious potential for introducing renewable energy instead, and to facilitate replacement the Danish government first banned any further installation of oil boilers in new buildings in 2013, and in 2017 also banned installation of oil boilers in existing buildings (Danish Energy Agency, 2011).

A.1.5 ENERGY CONSUMPTION IN TRANSPORT AND INDUSTRY

The use of renewable energy in the transport and industry sectors is still relatively limited. Figure 9 shows that in the transport sector it is still gasoline and diesel that are primarily used, due to their use in road transportation. The use of renewable fuels and electricity for transport remains limited in Denmark, and is an area in need of future attention if the renewable energy ambitions are to be fulfilled (Hagos, 2020).

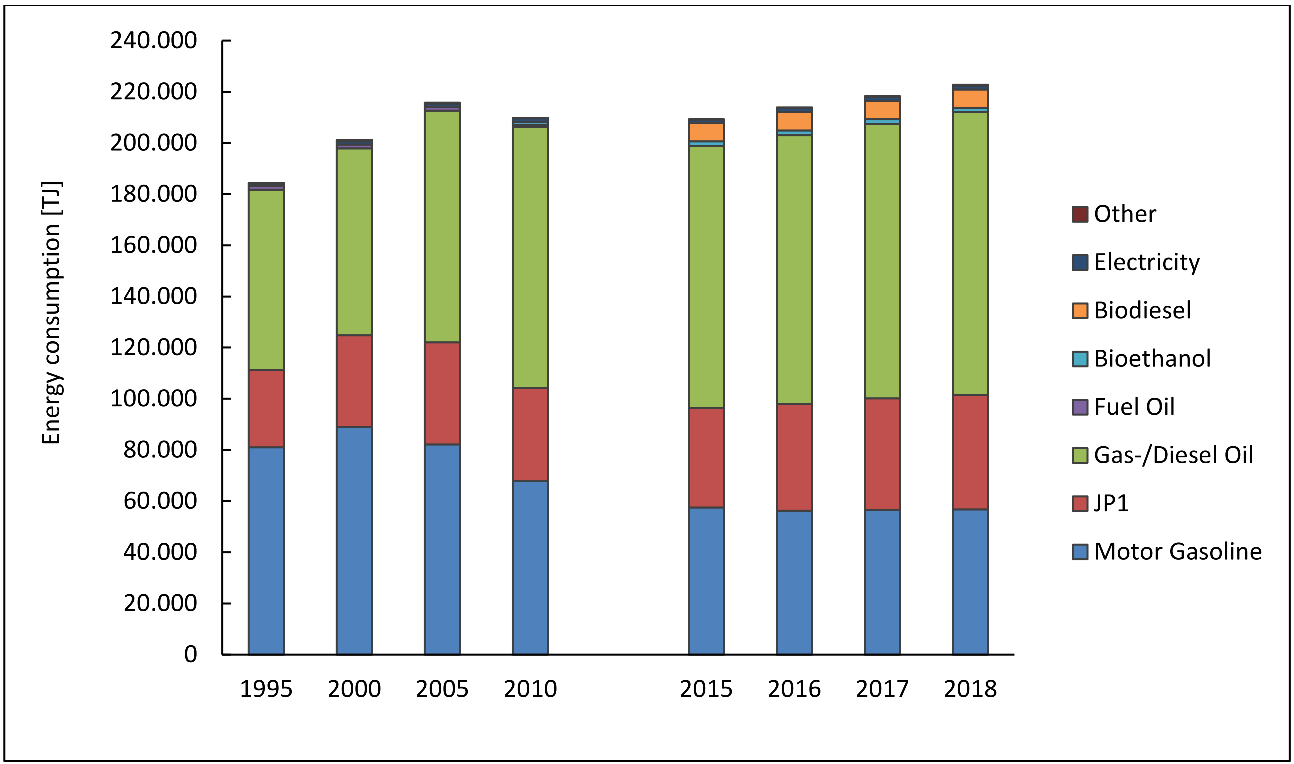

Figure 9: Energy consumption in the transport sector (Danish Energy Agency, 2019).

Compared to many other countries, Denmark is not home to many large energy-intensive industries. An overview of energy demands can be seen in Figure 10. The manufacturing industry is the primary energy consumer, this includes e.g. plastic, glass, and cement manufacturing, but also food and drink production, and to a lesser extent oil refineries, metal production and chemical industries.

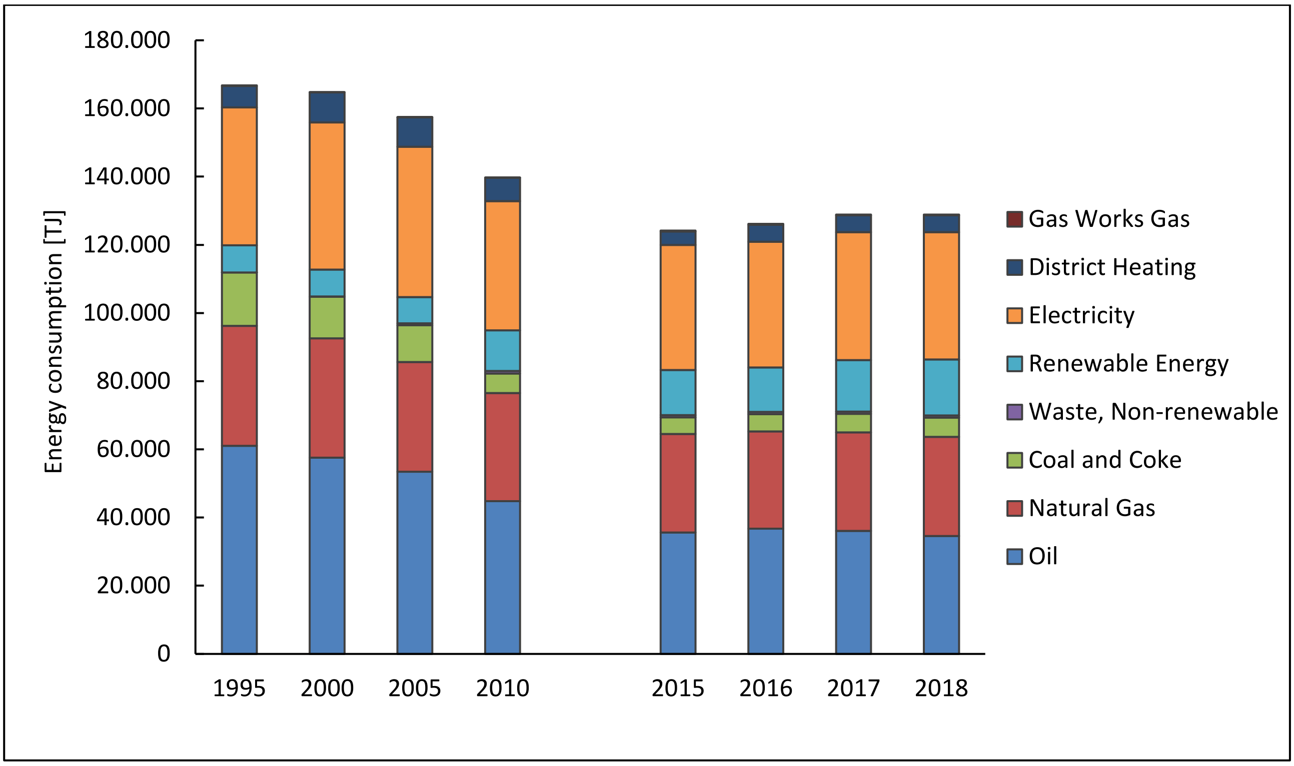

Figure 10: Energy consumption in the industry sector (Danish Energy Agency, 2019).

A benefit of the extensive Danish district heating sector is that excess heat from industrial processes can be integrated in the energy system. Excess heat is an important part of many district heating systems already, and especially high-temperature excess heat e.g. from cement factories or paper production is valuable. However, in combination with heat pumps and lower supply temperatures in the district heating grids, low-temperature processes can also provide excess heat for district heating (Bühler, 2019).

FUTURE SCENARIOS FOR THE ENERGY SYSTEM

Energy system modelling and scenario development has been a well-established practice in Denmark for a long time, and such scenarios have been important tools for Danish energy planning (Veenman, et al., 2019). Scenarios for the future Danish energy system have been developed by several different actors, both public authorities, private organizations, and research institutions. This chapter introduces some of the most recent scenarios, to provide insights into how the Danish energy system may develop in the future. This is not intended to be a comprehensive overview of all existing scenarios; the purpose is merely to present some of the potential alternatives for the future Danish energy system based on renewable.

A.1.6 DANISH ENERGY AGENCY'S ENERGY SCENARIOS FOR 2020, 2035 AND 2050

In 2013 the Danish Energy Agency published five different energy scenarios for the future Danish energy system. The scenarios were developed based on the energy agreement in 2012 to investigate different potential futures for the Danish energy system. The five scenarios were:

- *"The **wind scenario** is designed to use bioenergy corresponding more or less to what Denmark itself can supply, i.e. around 250 PJ. This does not mean the bioenergy necessarily has to be Danish, but that it can be supplied from Denmark. This requires massive electrification within transport, industry and district heating, as well as a considerable expansion with offshore wind turbines. In order to keep the consumption of bioenergy low, hydrogen is produced and used to upgrade biomass and biogas to make it last longer.*
- *The **biomass scenario** is designed to an annual bioenergy consumption of around 450 PJ. This entails a certain volume of net biomass imports in normal years (around 200 PJ) No hydrogen is involved.*
- *The **Bio+ scenario** entails a fuel-based system similar to that we have today, with the only exception that coal, oil and natural gas are replaced by bioenergy. Fuel consumption will be around 700 PJ. No hydrogen is involved.*
- *The **hydrogen scenario** is designed to simulate very small bioenergy consumption (under 200 PJ). This entails considerable use of hydrogen and considerably more wind power than in the wind scenario.*
- *The **fossil-fuel scenario** outlines a theoretical situation in which fossil fuels are used and all policy targets are disregarded. The fossil-fuel scenario illustrates an alternative that focusses mainly on 'lowest possible costs'"* (Danish Energy Agency., 2014)

All the scenarios also assume "large" energy savings in Denmark, and a smaller expansion of the current district heating systems. The fossil-fuel scenario is used as a reference model and will not be further discussed here.

Based on the scenario analysis it was concluded that the biomass potential in Denmark is limited, as such, a choice between a large import of biomass and an electricity-based system should be made. Production of biofuels or electrofuels is needed for use in aviation, lorries, etc., and if this fuel production is placed in Denmark, it could provide large amounts of excess heat for the district heating systems in Denmark. The district heating systems provide the option of increased flexibility of the energy system at moderate costs, where there in all scenarios is increased utilisation of excess heat from industry and fuel production alongside waste incineration, geothermal energy, solar thermal, smaller gas-fired CHP units, electric-driven heat pumps and biomass boilers. The individual heat demand is in all scenarios delivered by a mix of electric-driven heat pumps and biomass boilers with solar thermal as a supplement. (Danish Energy Agency., 2014)

A.1.7 ENERGINET'S SYSTEM PERSPECTIVE 2035

The Danish national transmission system operator of the electricity and gas networks Energinet has developed energy system scenarios for the Danish energy system in 2035 and 2050 (Energinet, 2018). These scenarios function as the long-term outlook for Energinet, used for planning future investments in infrastructure, developing market design and operation strategies, and as a contribution to public and political discussions. The scenarios were developed using input data from ENTSO-E's "Ten Year Network Development Plan" (TYNDP) from 2018 to project the development in the surrounding countries. Based on TYNDP from 2018 Energinet states three different scenarios for the potential future Danish energy system to understand the consequences of the different developments. The three scenarios are:

- **Global climate action** (GCA), where Europe is ambitious in relation to the green transition with a strong collaboration between the countries.
- **Distributed Generation** (DG), also an ambitious green transition, however, it is more national, local and individual solutions that are used for the transition.
- **Sustainable transition** (ST), the least ambitious green transition scenario, however, with increasing amount of wind power and PV due to decreasing costs of these technologies.

In the scenarios Energinet finds that the Danish electricity production in 2050 will increase to around 73-82 TWh/year depending on the scenario with GCA having the highest Danish electricity production and ST having the lowest. The production of electricity is mostly from wind power providing around 75-80% of the total electricity production with photovoltaics producing around 17-20%, meaning that nearly all internal electricity production is from variable renewable electricity production, with only a small amount of internal electricity production from CHP plants or power stations. The scenarios also find a substantial import and export of electricity, each being around 29-40 TWh/year, however, the scenarios are created so that the yearly import of electricity correspond to the yearly export of electricity, so that on yearly basis the net import of electricity is close to zero. Part of the import is transitioned through Denmark to be used in other countries. To facilitate the large import and export of electricity the transmission capacity to surrounding countries is expanded from around 6.5 GW in 2020 to 10.4 – 12.7 GW in 2050. On the consumption side the traditional electricity demand is around 47-53% of the total demand. The transport sector is expected to consume around 21-23% of the total electricity demand, the heating sector around 16-17% and the production of electrofuels 8-16%.

In the district heating sector in 2050, the production of heat is mainly from electric-driven heat pumps that produce 36-46% of the total production, followed by fuel boilers producing 21-30% and excess heat from the electrofuel production supplying 18-27%. CHP only supply around 4-12% as it also only supplies a relatively small amount of electricity. For the individual heating 80% is provided by electric-driven heat pumps supplemented by solar thermal, 18% by fuel boilers and 2% is supplied by direct electric heating.

A.1.8 IDA'S CLIMATE RESPONSE

The Danish Society of Engineers (IDA) regularly publish scenarios for the future Danish energy system, with the first one being published in 2006 and the newest being published in 2021. Here the scenario for 100% renewable energy from the 2021 report is shown (Lund, et al., 2021). The scenario focuses on the year 2045 with the goal of 100% renewable energy, however, the publication also includes an in-between scenario for 2030 with the 70% CO_2 reduction target. The scenario is developed based on the concept of Smart Energy System, in which synergies between energy sectors are exploited to increase energy efficiency and reduce costs. Besides changes to the energy transformation, the scenario also includes significant energy savings at the end users. Figure 11 shows the primary energy supply of the entire energy system in 2030 and 2045 (Smart Energy Denmark 2045), alongside a simulated primary energy supply in 2020 for reference.

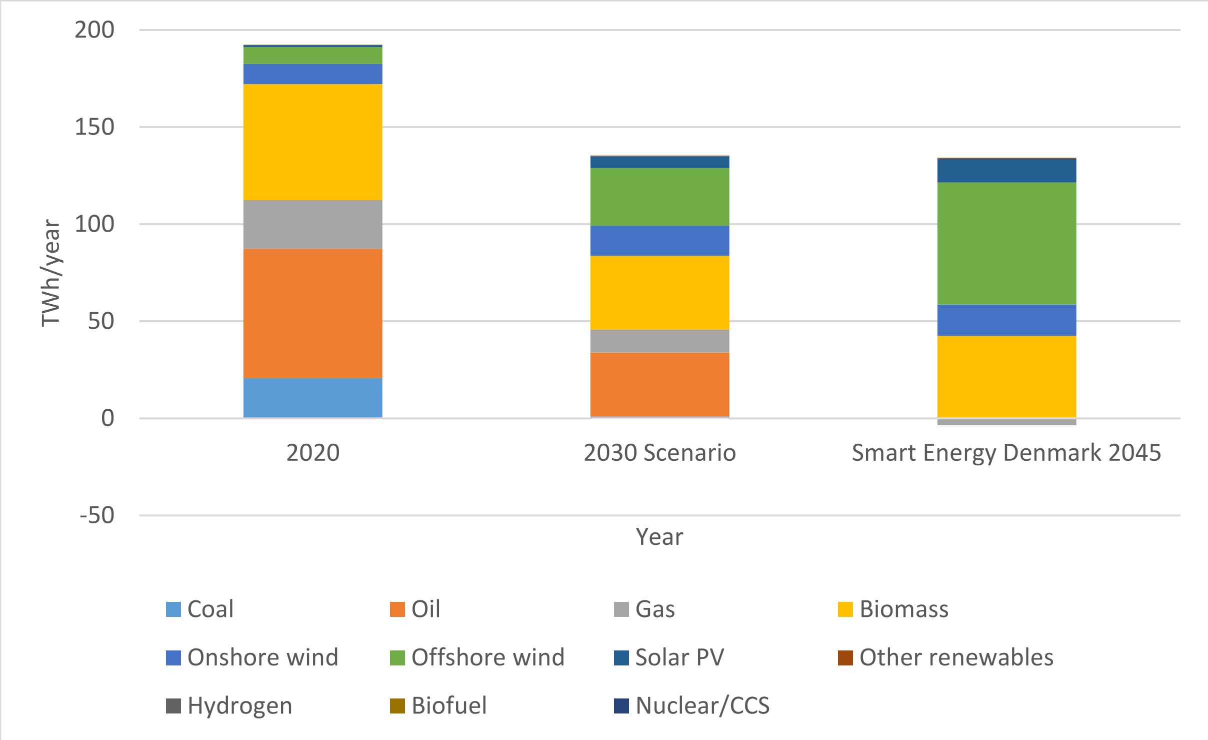

Figure 11: Primary energy supply of the entire Danish energy system in 2020 and the two IDA's Climate Response scenarios (Lund, et al., 2021)

As shown in Figure 11, the IDA scenarios suggest a significant shift from fossil fuels to especially wind power alongside the use of biomass, PV, geothermal heat and solar thermal. This also means a significant shift to using more electricity in the energy system, with the electricity production going from around 36 TWh/year to around 100 TWh/year. The electricity is especially used for the production of electrofuels used for producing fuels for the parts of the transport sector that cannot be directly electrified, such as aviation and long-haul road transportation, which in the 2045 scenario are using more than 30% of the produced electricity. This is followed by electricity for direct electrification in the transport sector and electricity for heating purposes. In the heating sector the district heating systems are expanded so that they cover 63% of the total heat demand in the 2045 scenario, up from around 50% in 2020. The district heating production is especially from excess heat sources in industry, data centres and the production of electrofuels making up around 27% of the yearly district heating production in the 2045 scenario. This is followed by 27% from electric-driven heat pumps, 24% from geothermal heat, 10% heat from waste incineration CHP units, 8% from gas-fired CHP units, 6% from solar thermal, and around 1% from fuel boilers and electric boilers. The individual heating demand is supplied mainly by individual heat pumps supplemented by solar thermal.

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