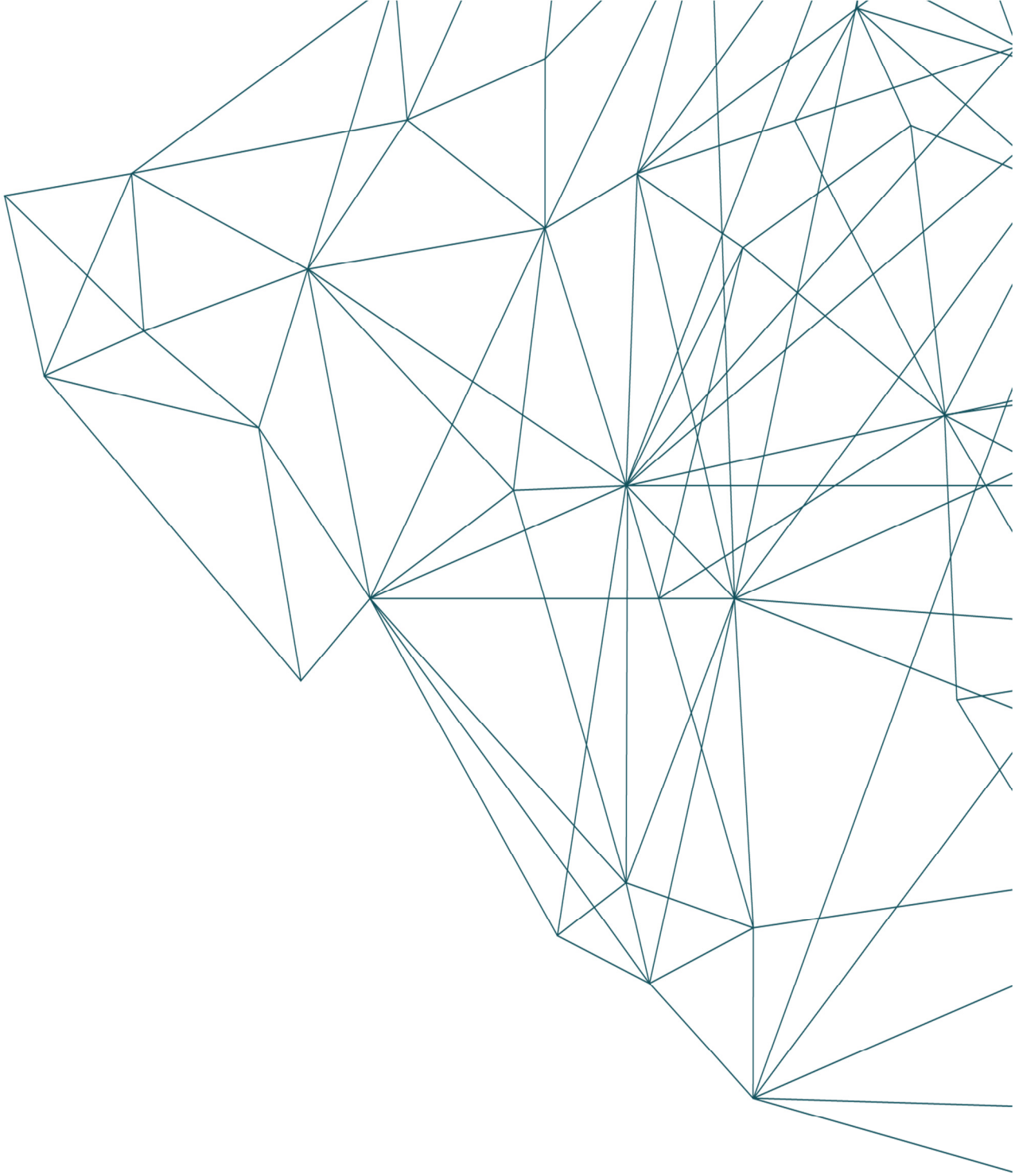


Environmental Report 2018

Environmental report for Danish electricity and CHP for 2017 status year

Contents

Pursuant to the Danish Electricity Supply Act, Energinet reports on the most important environmental issues associated with the generation of electricity and CHP in Denmark.

The report contains the following statutory descriptions:

- Status on environmental impacts from Danish electricity and CHP in 2016.
- Forecasts for 2017-2026 for electricity generation, fuel consumption and emissions to air.

For a further description of the methods and data basis including analysis assumptions for the Environmental Report, please refer to the individual documents at www.energinet.dk. More detailed data are available, including the data on which the figures are based.

The final analysis assumptions will be published after the presentation of this report, for which reason the forecasts are based on the analysis assumptions from 2017.

Electricity consumption and generation 2017

Developments in market and climatic conditions have a considerable bearing on the generation of electricity and CHP and thus on the environmental impact of these activities in Denmark. Special conditions in 2017:

- The electricity market in Denmark in 2017 was characterized by a larger production from wind power, lower export capacity and higher electricity prices than 2016. The average Danish electricity price rose by approx. 10 per cent in 2017.
- With a wind index of 90.2, 2016 was a year with few wind resources. In comparison, in 2017 the energy content of the wind was 102,3 per cent.
- The available exchange capacity was lower in 2017 compared to 2016. Especially the export capacity to Norway and Sweden were limited in 2017.

Table 1 and Table 2 show the change in selected electricity generation statistics in Denmark from 2016 to 2017. A more detailed breakdown of electricity generation can be seen in Table 5.

Key figures for electricity generation in Denmark	2016	2017	Change
	GWh	GWh	%
Net electricity generation	28,930	29,453	2
Net import	5,057	4,563	-
Consumption (including grid losses)	33,987	34,015	0.1
Breakdown of electricity generation	**GWh**	**GWh**	**%**
Electricity from central power stations	11,494	9,856	-14
Electricity from local CHP plants	3,891	4,013	3
Electricity from wind turbines	12,782	14,777	16
Electricity from photovoltaic cells	744	789	6
Electricity from hydroelectric power	19	18	-7

Table 1. Change in power generation from 2016 to 2017.

In Denmark, there was a generation deficit of 4,563 GWh in 2017, which means that electricity generation was 13 per cent lower than consumption on an annual basis. The last generation surplus was seen in the dry year 2010. 2017 was a typical wet year with net exports to Germany and net imports from Norway and Sweden. In 2017, imports from both Norway and Sweden were approx. 3 TWh, while 1.4 TWh was exported to Germany.

The electricity generation from photovoltaic cells and wind power set new records in 2017. The increase in production from photovoltaic cells, can be explained by an increase in the installed capacity of approx. 7 per cent. The increase in generation from wind power is mainly due to better wind conditions in 2017 compared to 2016, but also an increase in the capacity of approx. 5 per cent.

The thermal electricity generation in Denmark was at the next-lowest level in the historical period for which Energinet has data available (1990 onwards). Power plants based on coal or natural gas both had, on average, poorer market conditions in 2017 compared to 2016.

Breakdown of electricity output by main fuel	2016	2017	Change
	MW	MW	MW
Wind power	5,250	5,497	247
Photovoltaics	845	908	63
Hydroelectric power	7	7	0
Biogas	118	118	0
Biomass	1,507	1,582	75
Waste	351	351	0
Natural gas	2,151	2,150	-1
Oil	722	723	-1
Coal	1,604	1,567	-37
Other	26	26	0
Total	**12,582**	**12,928**	**346**

Table 2. Change in electricity output from 2016 to 2017.

Table 2 is based on Energinet's base data at year-end. Installed capacity is stated next to the power stations' main fuel. The figures do not include partly operational or preserved power stations.

The change in power station capacity was limited in 2017. A new biomass fueled power station in Lisbjerg near Aarhus was commissioned in 2017. It has a electrical capacity of 38 MW. Bornholms Energi & Forsyning have converted a coal fired power station rated at 37 MW to use biomass, also in 2017. Skærbækværket has been converted from natural gas to biomass, but its main fuel is still listed as natural gas in table 2.

Electricity consumption and generation 1990-2027

Figure 1 below shows the development in electricity consumption and generation in Denmark in the 1990-2027 period. The peaks in 1996, 2003 and 2006 were due to dry years with high market prices as a result of low water levels in Nordic reservoirs and thus increased power generation in Denmark.

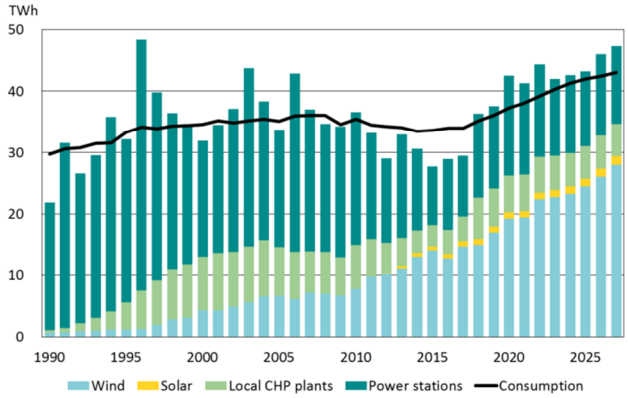


Figure 1. Electricity consumption and generation in Denmark

From 1990 to 2017, electricity consumption in Denmark increased by approx. 15 per cent, peaking at 36.1 TWh in 2008, but then followed by an approx. 6 per cent fall. The forecast is based on an increase in electricity consumption of just under 22 per cent. Part of this increase is explained by the expected establishment of several large data centres and the increased implementation of heat pumps and electric vehicles.

Central power station generation is expected to be at a higher level for the duration of the forecast period relative to the 2017 status year. The forecast period is characterised by the decommissioning of a large number of coal and natural gas-fired central power stations or the conversion of these power stations to firing with more biomass.

Local generation in Denmark grew steadily in the period from 1990 to 2000 in step with the increasing number of local CHP plants in Denmark. After 2004, local generation has been declining as many of the local CHP plants have started selling their electricity on market terms. At the beginning of the forecast period, local generation is expected to be higher than in 2017, followed by an assumed gradual decline towards 2027.

The 2012-2017 period saw a dramatic increase in the number of photovoltaic cells in Denmark. At the end of 2027, the estimated photovoltaic cell capacity is 1,468 MW. During the same period, the electricity generation from photovoltaic cells is expected to increase to approx. 1.4 TWh or 3 per cent of the expected future electricity consumption in Denmark.

There has been a great expansion of wind power in Denmark since 1990. In 2017, wind power thus covered approx. 43.4 per cent of the Danish electricity consumption relative to only 2 per cent in 1990.

Figure 2 shows the expected development in wind power generation towards 2027 (left axis). The curve shows the share of total electricity consumption based on wind power year by year (right axis).

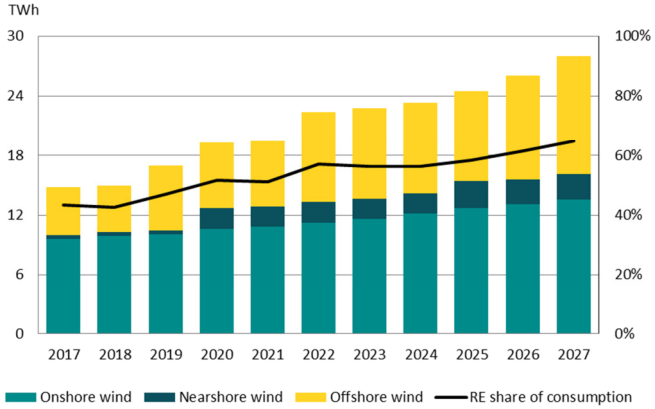


Figure 2. Wind power generation 2017-2027

The assumption is that there will be a considerable increase of wind power generation in Denmark in the period up to 2027. Total electricity generation from land-based, near-shore and offshore wind turbines in Denmark is expected to be 28 TWh in 2027, corresponding to approx. 65 per cent of electricity consumption in Denmark.

Much of the increase in wind power generation in the forecast period is expected to come from wind turbines at sea, partly from near-shore wind turbines and partly from three new offshore wind farms with total capacity of approx. 1,600 MW. In 2027, offshore wind power generation is expected to constitute approx. 50 per cent of the total wind power generation in Denmark, up from 35 per cent in 2017.

In 2027, electricity generation from land-based wind turbines is expected to be approx. 4 TWh higher than in 2017, which can be explained by an increase in both capacity and full-load hours (generation per installed MW). Some of the added land-based capacity will be

counterbalanced by the decommissioning of other wind turbines, but the new land-based wind turbines are generally expected to have more full-load hours than the decommissioned ones.

Fuel consumption 2017

The development in the fuel consumption for the generation of electricity and CHP from 2016 to 2017 can be seen in Table 3.

Fuel consumption	2016	2017	Change
	PJ	PJ	%
Coal	83.90	60.90	-27.4
Natural gas	25.84	23.52	-9.0
Oil	3.30	3.08	-6.8
Waste	34.94	32.88	-5.9
Biogas	4.82	5.42	12.3
Biomass	45.29	60.61	33.8
Total	198.09	186.42	-5.9

Table 3. Change in fuel consumption from 2015 to 2016

In 2017 a new biomass fuelled power station was commissioned in Lisbjerg near Aarhus, and Skærbækværket was converted to also use biomass as a fuel. Studstrup Power Station's unit 3 and Avedøre Power Station's unit 1 were both commissioned in 2016 following a conversion from coal to biomass. Therefore 2017 will be the first full production year. These new stations and conversions results in a significant increase in biomass consumption in 2017 compared to 2016.

Fuel consumption 1990-2027

A time series for the development in fuel consumption by Danish power stations and CHP plants for the period 1990-2027 is shown in Figure 3.

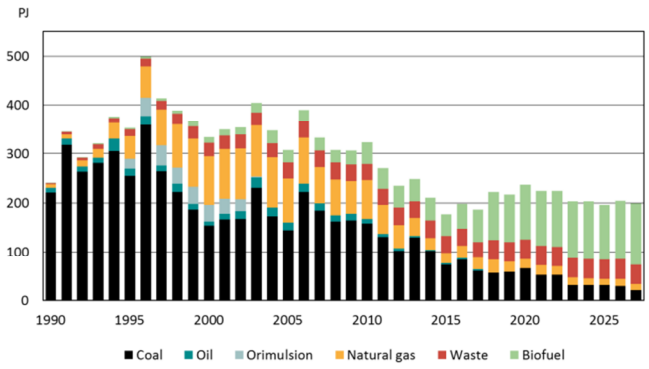


Figure 3. Fuel consumption in Denmark

From 1990 to 2017, coal went from accounting for 92 per cent to 33 per cent of fuel consumption for Danish electricity and CHP generation. This was due to an expansion of local CHP plants based on natural gas as well as the conversion of several power station units to natural gas and biomass. The consumption of coal has generally been decreasing since 1990, but variations are seen over the years as the coal-fired power stations have continuously adapted their output to demand.

Moreover, the period since 2010 has been characterised by a general fall in thermal electricity generation in Denmark and thus not least in the consumption of fossil fuels. In the period from 2010 to 2017, the consumption of coal, natural gas and oil has decreased by 62 per cent, 70 per cent and 67 per cent. During the same period, the consumption of waste has been relatively constant, while the consumption of biofuels (biomass and biogas) haven risen by approx. 50 per cent.

In 2017, biofuels (biomass and biogas) accounted for 35 per cent of power station fuel consumption in Denmark. The consumption of biomass for electricity and CHP generation is expected to increase significantly in Denmark towards 2027. In fact, biofuels where, for the first time, the commonly used fuel at Danish power stations in 2017. According to the forecast, the share of fuel consumption derived from biofuels will increase to 63 per cent in 2027.

A further reduction in the utilisation of fossil fuels by Danish power stations is expected in the forecast period as a number of central power stations are expected to be converted to firing biomass or decommissioned. Towards 2027, a gradual decrease in the capacity of local CHP plants based on natural gas has been assumed.

Renewable energy

Table 4 shows the development in renewable energy from 2016 to 2017.

Development in renewable energy	2016	2017	Change
	GWh	GWh	%
Net electricity generation	28,930	29,453	2
Consumption (including grid losses)	33,987	34,015	0.1
Breakdown of electricity generation	**GWh**	**GWh**	**%**
Wind, solar and hydroelectric power	13,545	15,584	15
Electricity from thermal generation based on RE fuels	4,266	5,459	28
Electricity from thermal generation based on non-RE fuels	11,119	8,410	-24
Share of renewable energy	**%**	**%**	**%-points**
Wind power share of net generation	44.2	50.2	6.0
Wind power share of consumption	37.6	43.4	5.8
RE share of net generation	61.6	71.4	9.9
RE share of consumption	52.4	61.9	9.5

Table 4. Development in renewable energy from 2016 to 2017.

Total electricity generation from renewable energy sources was 21,043 GWh in 2017 and constituted 71.4 per cent of total electricity generation in Denmark. Compared with 2016, the key figures for wind power share and the RE share increased in 2017 due to more wind power generation and increased use of biomass as fuel.

Share of renewable energy in 2017

Electricity generation from renewable energy sources in Denmark is dominated by wind power, but also includes electricity generated from hydroelectric power, photovoltaic cells, biogas, biomass (straw and wood) and biodegradable waste fractions. Figure 4 shows the breakdown of RE-based electricity generation in Denmark in 2017.

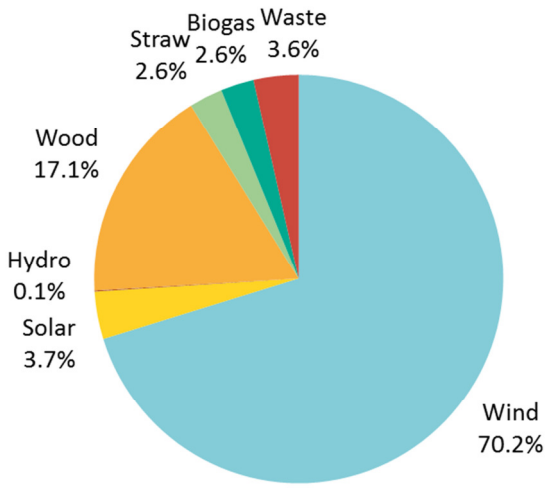


Figure 4. Breakdown of RE-based electricity generation in Denmark

Electricity generation from renewable energy sources 10 years ahead

Figure 5 shows the expected development in electricity generation from renewable energy sources in the next ten years (left axis). The curve shows the share of total electricity generation based on renewable energy sources year by year (right axis).

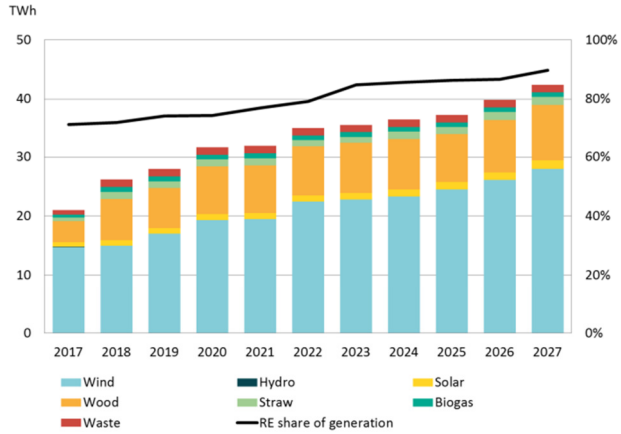


Figure 5. Electricity generation from renewable energy sources

The RE share of electricity generation in Denmark is expected to be increased to approx. 90 per cent in the course of the next ten years, which corresponds to a doubling of the current level of RE-based electricity generation.

The increase in RE generation is primarily expected to come from an increased expansion of wind power as well as the conversion of a number of central power stations to wood firing. In 2027, wind power is expected to account for two thirds of total electricity generation from RE sources, while wood is expected to account for 23 per cent.

CO_2, SO_2 and NO_x emissions

According to the most recent national statement from DCE – Danish Centre for Environment and energy from 2016 of total Danish emissions of CO_2, SO_2 and NO_x, the Danish electricity supply industry contributes 31 per cent, 24 per cent and 9 per cent, respectively.
The development in emissions of these three substances from Danish electricity and CHP generation in the period 1990-2017 is shown in Figure 6. Since 1990, emissions of CO_2, SO_2 and NO_x have fallen by 61 per cent, 98 per cent and 89 per cent, respectively.

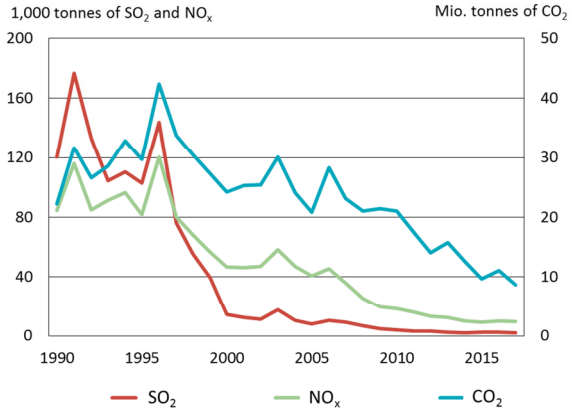


Figure 6. Emissions of CO_2, SO_2 and NO_x in Denmark

The decrease in SO_2 emissions since 1990 can be attributed to the use of fuels with a lower sulphur content and the installation of desulphurisation units at the large power stations and waste-fired plants. SO_2 emissions are so low that fluctuations in generation from individual power stations are clearly discernible. Despite the general improvements in the industry as a whole, increases in emissions may therefore be seen in some years. NO_x emissions have primarily been reduced through the installation of deNO_x units and low-NO_x burners at the large power stations.

Towards 2027, SO_2 and NO_x emissions are expected to remain at a consistently low level.

CO_2 emissions follow the development in the firing of fossil fuels at the Danish power stations, and substantial variations are therefore seen in the historical values, depending on Denmark's electricity trading with neighbouring countries.

The primary reason for the fall in CO_2 emissions since 1990 is the low electricity prices seen in recent years, which have led to a substantial decrease in thermal electricity generation based on fossil fuels. Also, over a number of years, Danish electricity and heat generation plants have been converted to less CO_2-intensive fuels such as natural gas, coupled with an increased use of renewable energy sources.

The conversion of several central power plants to biomass has a strong impact on the CO_2-emissions from Danish electricity and CHP production, which has decreased by 22 per cent from 2016 to 2017.

Figure 7 shows the development in CO_2 emissions from the Danish electricity supply industry in the 2017-2027 period (left axis). The curve shows specific CO_2 emissions per generated kWh of electricity in Denmark (right axis). Energinet does not make a projection of the environmental impact statement for electricity, which describes the environmental impact from the consumption of 1 kWh of electricity, and which is therefore corrected for exchanges of electricity with neighbouring countries.

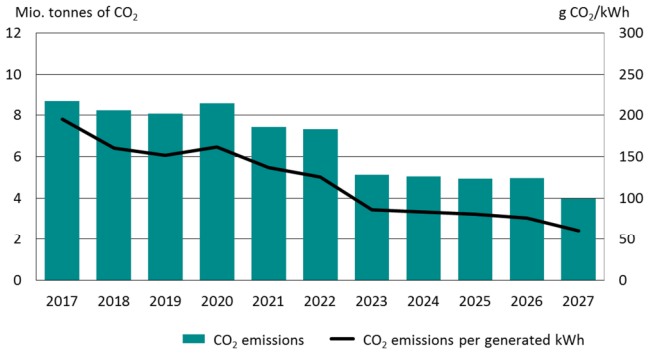


Figure 7. CO_2 emissions 2017-2027

A further 55 per cent reduction in CO_2 emissions is expected to be achieved by 2027 based on the assumed conversion of several central power stations from coal and natural gas to biomass as well as the anticipated gradual reduction of capacity at natural gas-fired local CHP plants.

The average CO_2 emissions from the generation of 1 kWh of electricity in Denmark in the same period are expected to decline from 194 g per kWh in 2017 to about 61 g per kWh in 2027.

Other environmental impacts

In Table 5, Energinet also reports on emissions of the greenhouse gases CH_4 (methane) and N_2O (dinitrogen oxide) as well as particles, NMVOC (unburnt hydrocarbons) and CO (carbon monoxide). An overview of the

generation of residual products is also available. Time series for the period 1990-2027 are also available for the above-mentioned environmental impacts on the Energinet website in the form of a spreadsheet.

Key figures for Denmark 2015-2017	Note	Unit	2015	2016	2017
Power generation (gross generation, including internal consumption)	1	GWh	28,931	30,199	30,662
Power supply to the grid (net ex plant)	2	GWh	27,704	28,930	29,453
CHP generation	3	TJ	93,573	97,881	97,048
Electricity imports		GWh	15,645	14,976	15,218
Electricity exports		GWh	9,733	9,919	10,655
Transmission grid losses (AC and DC)	4	GWh	963	969	1,009
Consumption (sale to distribution)		GWh	32,653	33,018	33,006
Specification of net electricity generation					
Electricity from land-based wind turbines		GWh	9,300	8,132	9,597
Electricity from offshore wind turbines		GWh	4,833	4,650	5,180
Electricity from photovoltaic cells	5	GWh	605	744	789
Electricity from hydroelectric power		GWh	19	19	18
Electricity from biofuels		GWh	2,998	3,508	4,711
Electricity from waste		GWh	1,438	1,377	1,360
Electricity from natural gas		GWh	1,912	2,366	2,062
Electricity from oil		GWh	151	169	139
Electricity from coal		GWh	6,449	7,964	5,597
Emissions to air from electricity and CHP generation					
CO_2 (carbon dioxide – greenhouse gas)	6	Tonne	9,678,013	11,118,114	8,726,282
SO_2 (sulphur dioxide – acidifying gas) total emissions		Tonne	2,533	2,410	1,864
SO_2 from units ≤ 25 $MW_{electricity}$		Tonne	1,626	1,382	987
SO_2 from units > 25 $MW_{electricity}$		Tonne	907	1,028	876
NO_x (nitrogen oxides – acidifying gas) total emissions		Tonne	9,049	9,819	9,695
NO_x from units ≤ 25 $MW_{electricity}$		Tonne	4,795	5,146	5,266
NO_x from units > 25 $MW_{electricity}$		Tonne	4,254	4,673	4,429
CH_4 (methane – greenhouse gas)		Tonne	4,330	4,904	5,086
N_2O (dinitrogen oxide – greenhouse gas)		Tonne	174	191	179
NMVOC (unburnt hydrocarbons)		Tonne	764	899	957
CO (carbon monoxide)		Tonne	6,166	6,959	8,297
Particles		Tonne	289	329	297
Fuel consumption for electricity and CHP generation					
Coal		TJ	72,851	83,895	60,905
Oil		TJ	3,109	3,300	3,076
Natural gas, including refinery gas		TJ	22,228	25,838	23,525
Biogas		TJ	4,707	4,824	5,415
Biomass		TJ	38,982	45,291	60,613
Waste		TJ	35,062	34,938	32,884
Residual products from electricity and CHP generation					
Coal fly ash		Tonne	332,179	366,003	316,315
Coal slag		Tonne	37,385	43,889	60,705
Gypsum		Tonne	91,707	98,844	76,630
Other desulphurisation products (SDAP)		Tonne	33,637	29,996	17,375
Bioashes		Tonne	56,711	55,588	67,371
Slag (waste incineration)		Tonne	597,093	609,136	565,001
MSWI-ACP residues		Tonne	92,339	90,103	79,512

Table 5. Key figures for Denmark 2015-2017

Notes

Note 1. Gross electricity generation corresponds roughly to the energy supplied by the generator at the individual generation facilities. Part of the gross generation is consumed before delivery to the grid. This includes the electricity used by the power station to operate pumps, environmental facilities etc.

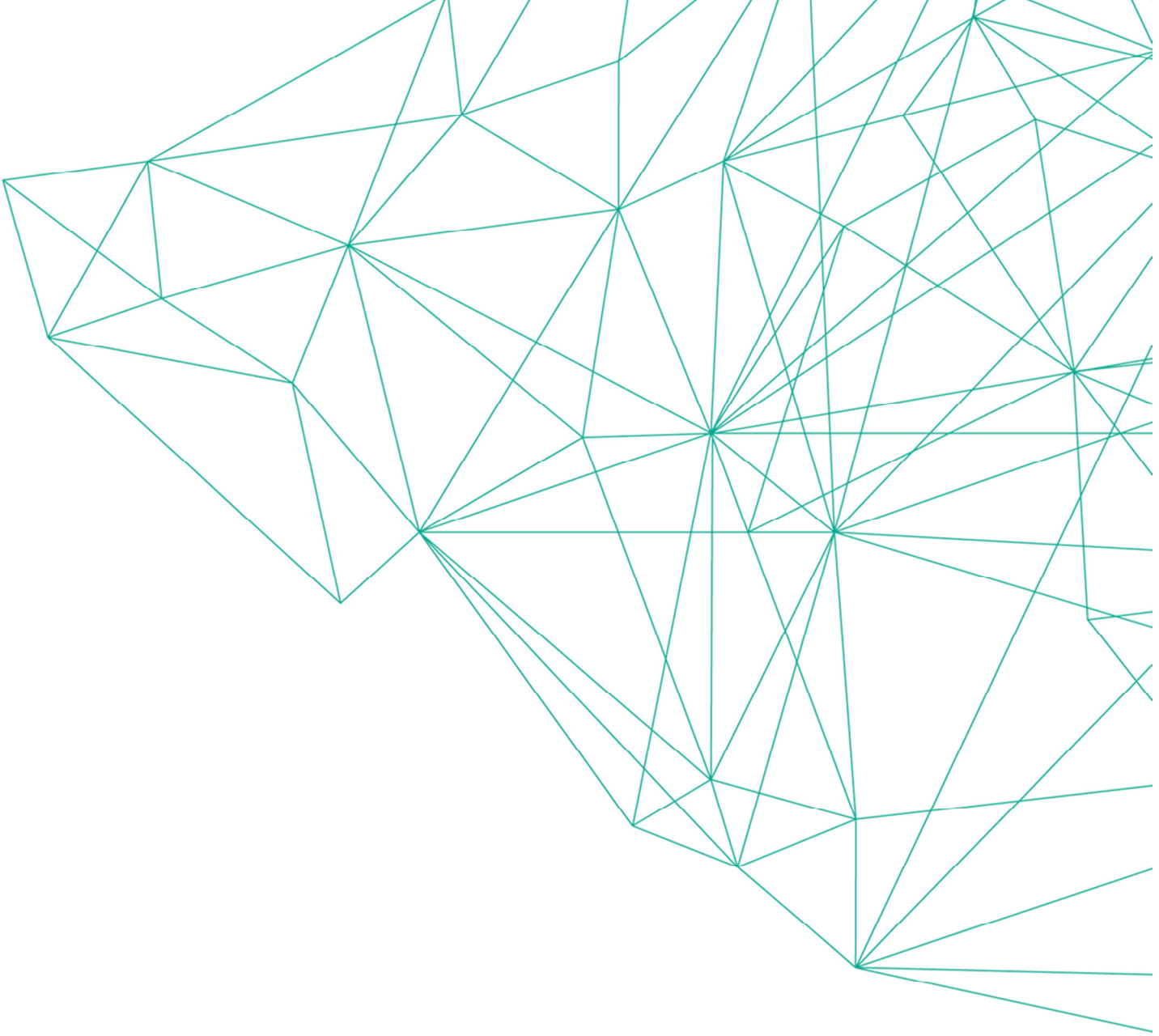
Note 2. The electricity supply is the volume of electricity from generation units available for domestic consumption or export via the grid. Electricity supplies are measured physically when discharged from the various generation units and recorded in Energinet's PANDA database.

Note 3. CHP generation includes gross generation of heat. No distinction is made between heat used for internal industrial processes, for process steam production and sold as district heating.

Note 4. This grid loss concerns the transmission grid (400 kV, 150 kV and 132 kV), the Great Belt Power Link and the HVDC substations on the international connections. Transit losses from international connections are included in these losses.

Note 5. The electricity generated by photovoltaic cells includes an estimate of the generation from photovoltaic cell units subject to net settlement.

Note 6. Under the Danish CO_2 Emission Allowances Act, waste is considered CO_2-neutral. However, waste contains large amounts of plastic, which is made from fossil fuels. According to the most recent assessment from DCE, fossil elements account for 45 per cent of the energy volume of the waste.



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