# STATUS QUO REPORT

Status quo of the electricity grid and potentials for energy flexibility in Southeastern Denmark and Northern Germany

**December 2020**

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# INDHOLDSFORTEGNELSE




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# EXECUTIVE SUMMARY - DANISH

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I Danmark og Tyskland øges andelen af vedvarende energi i elproduktionen. Denne udvikling er afgørende for omstillingen til et klimaneutralt samfund. Men en øgning af andelen fluktuerende vind- og solenergi skaber problemer med uoverensstemmelser i elproduktionen og efterspørgsel i tid og rum.

**Rumlig skift**

Områder med stor kapacitet for vind- og solenergi ligger typisk ikke tæt på områder med et stort energiforbrug, hvilket gør det nødvendigt at transportere elektricitet fra produktionen til områder med efterspørgsel. På nuværende tidspunkt opfylder det danske og tyske elsystem ikke altid det fulde behov for transport, hvilket betyder at den lokale overproduktion kan skabe flaskehalse i elsystemet. Fordi udbygning af elsystemet er omfattende og tidskrævende, opstår et behov for lokal lagring af energi, for at undgå nedregulering af produktion, indtil systemet er tilstrækkelig udbygget.

**Tidsmæssig skift**

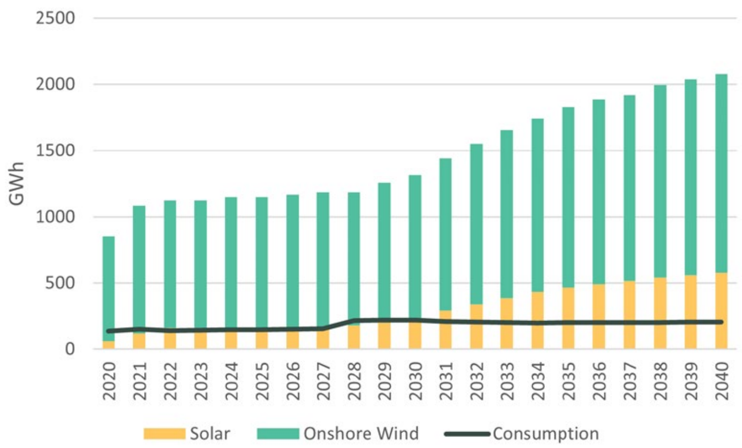
Over tid vil både Danmark og Tyskland have en 100% vedvarende energiproduktion baseret på høje andele vind- og solenergi. Når størstedelen af elproduktionen er fluktuerende, er det nødvendigt at forbrug og/eller produktion skifter tidsmæssigt for at tilpasse elproduktionen. Lagring og styring af efterspørgsel er afgørende for at muliggøre det tidsmæssige skift.

I Tyskland vil behovet for energilagring forsvinde når elsystemet er tilstrækkelig udbygget og forbedret. På vejen mod en 100% vedvarende elproduktion, vil behovet for lagring genopstå. I Danmark vil man nå målet om 100% vedvarende elproduktion inden 2030, og tempoet på denne omstilling skaber et overlap mellem kort- og langsigtede behov for lagring, og skaber dermed en sammenhængende efterspørgsel på disse teknologier.

Projektet DG STORE undersøger lokale muligheder for lagring og styring af efterspørgsel (demand side management - DSM) på Lolland og i Flensburg, som begge er områder med en overproduktion af el fra vedvarende kilder, og erfarer problemer med flaskehalse og nedregulering. Ved at kombinere et lokalt perspektiv på mulige løsninger med et systemperspektiv og at modellere indvirkningen af lokale løsninger for at øge fleksibiliteten i energisystemet, søger projektet at vise potentialet for lagringsteknologier i et klimaneutralt energisystem.

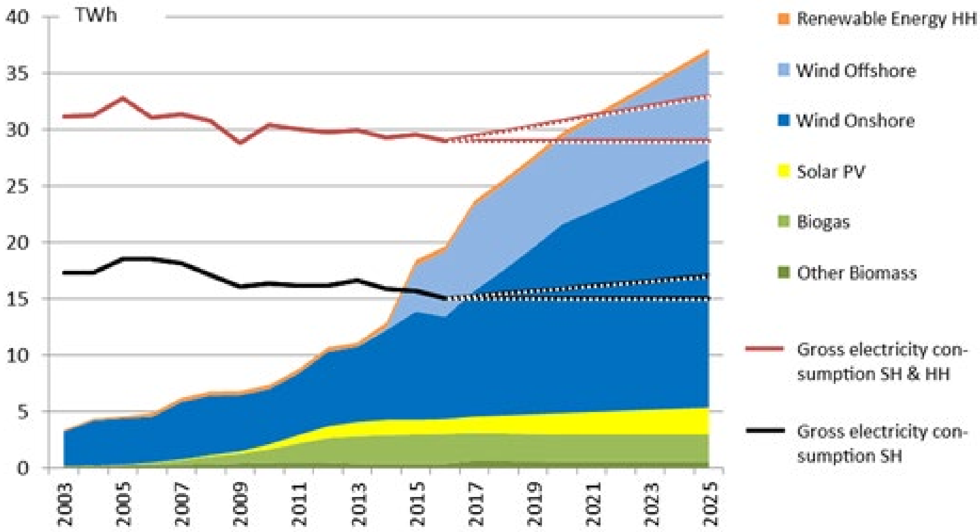
I 2019 var andelen vedvarende energi i elforsyningen 42,1% i Tyskland og 67,5% i Danmark [1] [2], primært fra vind, sol og biomasse. Tyskland sigter mod 80% vedvarende energi i elproduktionen inden 2050 [3], hvor Danmark, som tidligere nævnt, forventer at dække 100% af elforbruget med vedvarende energikilder inden 2030 [4].

Figur 1 og figur 2 viser overproduktion af elektricitet fra vedvarende kilder i Lolland Kommune og i Schleswig-Holstein, som er delstaten hvor Flensburg ligger. Andelen af el fra vedvarende kilder i den lokale elforsyning overstiger 100% i begge områder.



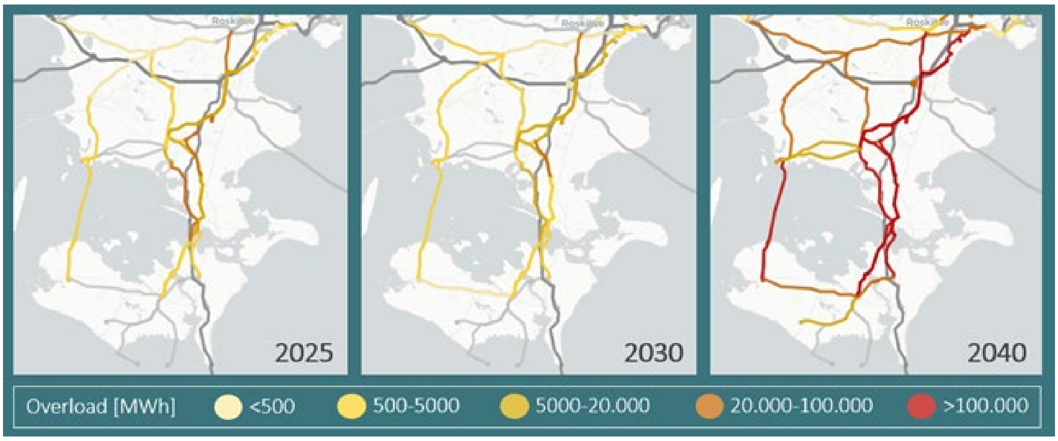

*Figur 1 Prædiktion af elproduktionen fra sol- og onshore vind samt elforbrug i Lolland Kommune, 2020-2040[1].Data fra Energinets Kapacitetskort [5] og Energinets Technology Data [6]*

1 *Produktionen udregnes fra kapacitet for vind og sol fra Kapacitetskortet multipliceret med årlige timer med fuld belastning (flh) estimater fra Technology Data (3500 flh/yr for onshore vind og 1000 flh/yr for sol). Produktionen udregnes ved at dividere denne produktion med forbrugsdækning procenter fra Kapacitetskortet.*




*Figur 2 Elproduktion fra vedvarende energikilder og brutto elforbrug i Schleswig-Holstein (SH) og Hamburg (HH) fra 2003 til 2025 (planlagt) [7] (oversat)*

Den lokale overproduktion forårsager problemer for elsystemet. Figur 3 viser at der forventes store overbelastninger i elsystemet tilsluttet Lolland i den nære fremtid. Samtidig med at produktionen af vind- og solenergi fortsætter med at øge, øges også behovet for transport. Når behovet for transport overstiger elsystemets kapacitet, opstår flaskehalsproblemet. Hvis der ikke findes muligheder for lokalt forbrug eller lagring, nedreguleres produktionen, med midlertidig reduktion eller nedlukning.

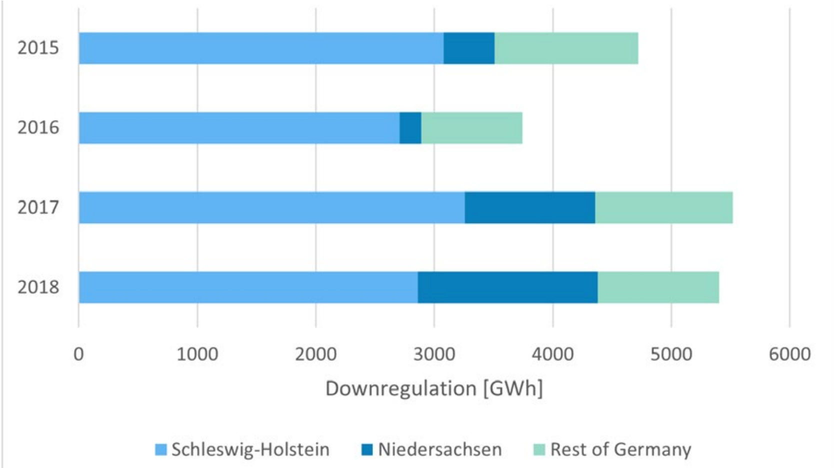



*Figur 3 Overskudsenergi per år i et N-1 scenario[2] for 2025, 2030 og 2040 fra Energinets Behovsanalyse for Eltransmissionsnettet 2020 [8]*

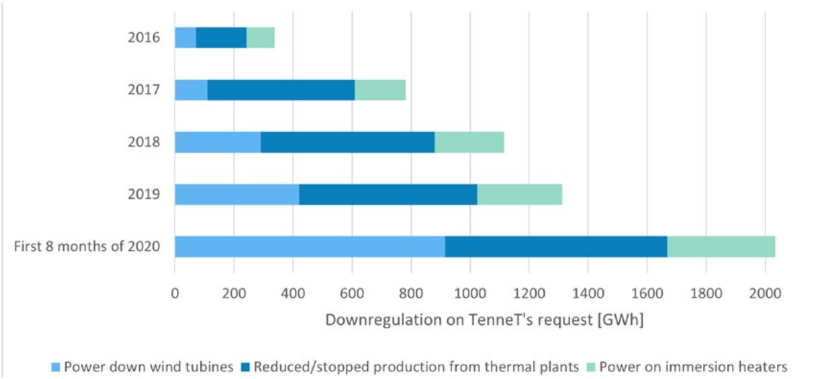
Hovedparten af den tyske nedregulering er sket i Schleswig-Holstein and Niedersachsen (se Figur 4). Dette er de to delstater med den største kapacitet for vindenergi I Tyskland, og med forholdsvis lav efterspørgsel på el. De estimerede finansielle tab grundet nedregulering i 2018 beregnes til 653.4 mio. Euros i hele Tyskland, og 294.4 mio. Euros i Schleswig-Holstein [9].

Danske elproducenter spiller også en rolle i at løse flaksehalsproblemet i Nordtyskland. Dette er den klart største grund for nedregulering i Danmark: 89% af nedreguleringen i Danmark i 2019 blev udført på forespørgsel fra TenneT, som er TSO i Schleswig-Holstein [10] [11]. I øgende omfang omfatter nedregulering vindturbiner. Se detaljer om specifikke reguleringer udført af danske aktører i Figur 5. Nedreguleringen er øget radikalt i 2020, delvist grundet høje vindniveauer, men også en øgning i den garanterede minimum transmission kapacitet forsynet af TenneT [12]. 8 % af potentialet i den danske produktion er blevet stoppet i de første 8 måneder af 2020 [13].

2 *Med alle komponenter i funktion på nær én*




*Figur 4 Nedreguleret elproduktion i hele Schleswig-Holsten, Niedersachsen og resten af Tyskland, 2015-2018. Data fra Agentur für Erneuerbare Energien 2020 [9]*




*Figur 5 Specifik regulering udført af danske aktører 2016-2019 på TenneTs forespørgsel. Data fra Statistik over Specialregulering [11] [13]*

Et system baseret på høje andele vind- og solenergi vil derfor kræve midlertidig og sæsonbaseret lagring som en løsning på kort- og langsigtede udsving i produktionen og samtidige flaskehalse i transmission og distribution. Dette er tilfældet i Danmark og Tyskland, og specielt i Flensburg og Lolland området, hvor DG STOREs showcases bliver testet. Hvis du ønsker at læse mere om løsningerne som demonstreres i projektet, besøg projekthjemmesiden www.dg-store.eu.

## Referencer for Executive Summary


*[1] Umweltbundesamt, "Erneubare Energien in Deutschland. Daten zur Entwicklung im Jahr 2019," Berlin, 2020. [Online]. Available: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2020-04-03_hgp-ee-in-zahlen_bf.pdf.*

*[2] Energistyrelsen, "Energistatistik 2019," 2020. [Online]. Available: https://ens.dk/sites/ens.dk/files/Statistik/energistatistik2019_dk.pdf.*

*[3] 50Hertz Transmission GmbH et al., "Szenariorahmen zum Netzentwicklungsplan Strom 2035, Version 2021-Entwurf der Übertragungsnetzbetreiber," 2020. [Online]. Available: https://www.netzentwicklungsplan.de/sites/default/files/paragraphs-files/Szenariorahmenentwurf_NEP2035_2021.pdf.*

*[4] Energistyrelsen, "Basisfremskrivning 2020 -Danmarks Klima-og Energifremskrivning," 2020. [Online]. Available: http://www.ens.dk/basisfremskrivning.*

*[5] Energinet, "Kapacitetskort 2020," 2020. [Online]. Available: https://energinet.dk/Om-publikationer/Publikationer/Kapacitetskort-2020.*

*[6] Energistyrelsen, "Teknologikatalog for produktion af el og fjernvarme," Apr. 2020. https://ens.dk/service/fremskrivninger-analyser-modeller/teknologikataloger/teknologikatalog-produktion-af-el-og (accessed Sep. 24, 2020).*

*[7] Landesregierung Schleswig-Holstein, "Bericht der Landesregierung: Energiewende- und Klimaschutzgesetz Schleswig-Holstein. Ziele, Maßnahmen und Monitoring 2018. Energiewende- und Klimaschutzgesetz Schleswig-Holstein," 2018. [Online]. Available: http://www.landtag.ltsh.de/infothek/wahl19/drucks/00800/drucksache-19-00818.pdf.*

*[8] Energinet, "Behovsanalyse for eltransmissionsnettet 2020," 2020.*

*[9] Agentur für Erneuerbare Energien, "Bundesländer-Übersicht zu Erneuerbaren Energien. Strom. Einspeisemanagement/Ausfallarbeit," 2020. https://www.foederal-erneuerbar.de/uebersicht/bundeslaender/W%7CBY%7CB%7CBB%7CHB%7CHH%7CHE%7CMV%7CNI%7CNRW%7CRLP%7CSL%7CSN%7CST%7CSH%7CTH%7CD/kategorie/strom/auswahl/880-einspeisemanagementa/sicht/diagramm/#goto_880 (accessed Nov. 25, 2020).*

*[10] Nord Pool, "Regulating power per area - Market data," 2020. https://www.nordpoolgroup.com/Market-data1/Regulating-Power1/ (accessed Oct. 28, 2020).*

*[11] Energinet, "Statistik over specialregulering 2016-2019," 2019, [Online]. Available: https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Specialregulering.*

*[12] Energinet, "Minimumskapacitet på DK1-DE/LU, jf. Joint Declaration og Tennet Commitment," 2020. https://energinet.dk/El/Nyheder-om-elsektorens-rammer-og-regler/2020/02/27/Minimumskapacitet-paa-DK1-DE-LU (accessed Dec. 22, 2020).*

*[13] M. Bernth, "Paradokset vokser: 2020 bliver rekordår for standsede vindmøller i Danmark," Ingeniøren, Oct. 2020, Accessed: Oct. 28, 2020. [Online]. Available: https://ing.dk/artikel/paradokset-vokser-2020-bliver-rekordaar-standsede-vindmoeller-danmark-239892.*

# INTRODUCTION

Moving towards a greener future includes relying increasingly on renewable energy. Wind and solar power have great potential for covering the electricity demand, but not necessarily when or where it is needed. In transitioning from traditional thermal power plants to increasing amounts of fluctuating electricity production from wind and solar, it is necessary to stabilize the electricity grid. This means expansion of the electricity grid itself, but also being able to shift consumption to match production.

The DG STORE project aims to showcase various electricity flexibility and storage solutions to analyze their potential for stabilizing the electricity grid. The showcases take place in Denmark and Germany, specifically Lolland in the Zealand Region and Flensburg in the Schleswig-Holstein region.

The seven showcases are:

**Case 1: Electrification of district heating**

**Case 2: Flexible energy consumption in retail**

**Case 3: Potential of balancing the energy system with electric busses**

**Case 4: Electric vehicle fleets as an accumulator in future energy systems**

**Case 5: Heat pump and energy storage in individual buildings**

**Case 6: Market research of smart homes and e-mobility**

**Case 7: Flexible charging of private electric vehicles and bicycles as direct and indirect energy storage**

This report shows the status quo of the German and Danish energy systems and the challenges facing Lolland and Flensburg. It explains why the seven showcases can play a key part in a successful transitioning towards a future energy system based on renewables.

To read more about DG STORE, visit: www.dg-store.eu.

# GERMANY'S ENERGY SYSTEM OVERVIEW

## Germany's energy consumption

Germany and Denmark are both part of the highly integrated European energy system. Due to size and economy, Germany has a larger impact on the European system. Germany consumed more than 20 % of the final energy consumption in Europe in 2018, while Denmark consumed only 1.5 % (Eurostat, 2020).

Germany is increasing its share of renewable energy but is at an early stage of its planned transition towards climate neutrality: Mineral oil and natural gas still contribute 70 % of the primary energy supply as shown in Figure 1. The share of brown coal declined sharply after the German reunification in the early 1900s due to retirement of old lignite fired power plants in the former GDR (German Democratic Republic). Nuclear energy has been phased out since around 2006. Electricity from coal and nuclear power was replaced by natural gas, mainly in the 1990s, and by renewable energy, especially after the year 2000. Oil has been replaced by natural gas in large parts of the heating sector, but its use has simultaneously increased in the transport sector.

The renewable energy generation is dominated by biomass and wind power as shown in Figure 2.

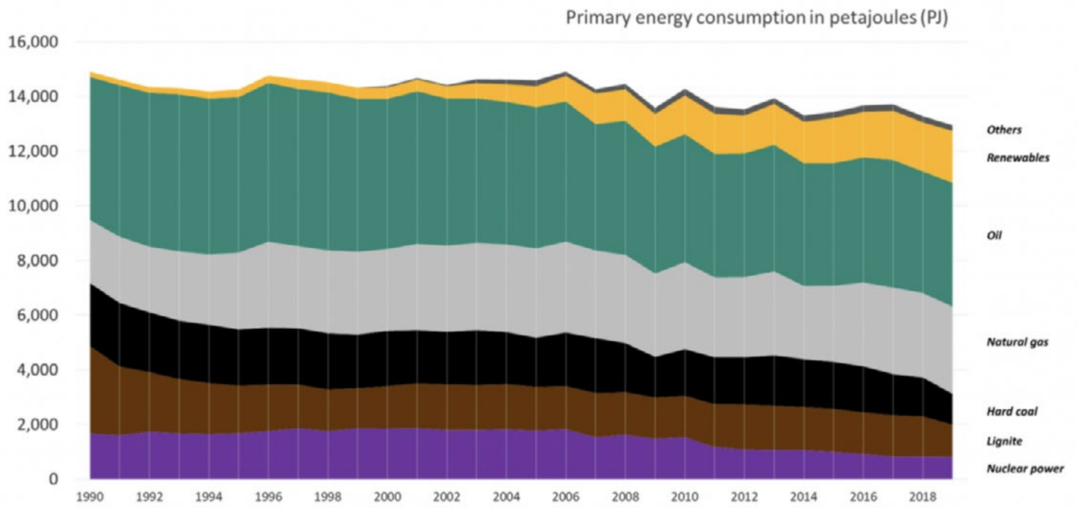



*Figure 1 Shares of different energy sources in Germany's primary energy consumption in PJ/a from 1990 to 2019 (Clean Energy Wire, 2020)*

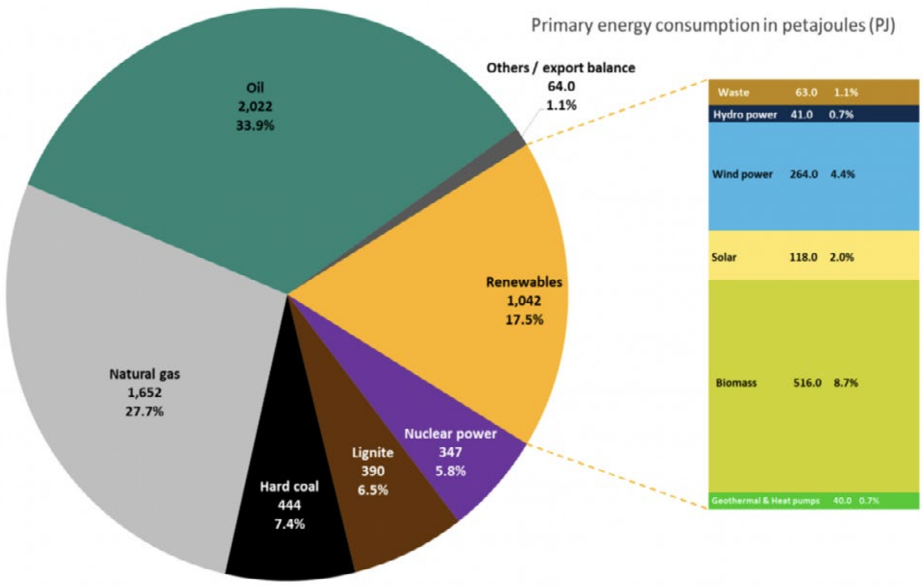



*Figure 2 Shares of different energy sources in Germany's primary energy consumption in PT/a in the first half of 2020 (Clean Energy Wire, 2020)*

## Germany's electricity generation and consumption

### The German electricity system historically

While the structure of the Germany energy consumption has been changing slowly, the electricity system has undergone a faster transition during the last thirty years. From a system dominated by coal and nuclear energy in 1990, now more than 40 % of the electricity generated is from wind, photovoltaic solar energy (PV) and biomass. More than 60 % of the nuclear capacity has been phased out, with the last nuclear plants to be shut down by 2022 (Bundesregierung, 2020).

Figure 3 shows the development of different energy sources in Germany electricity generation. The production from renewable sources is shown in Figure 4. In 2019 the renewable electricity generation was primarily based on wind, solar PV and biomass. Hydropower, which was the only renewable source in electricity generation before 1990, contributed only 8.3 % of the renewable electricity generation in 2019.

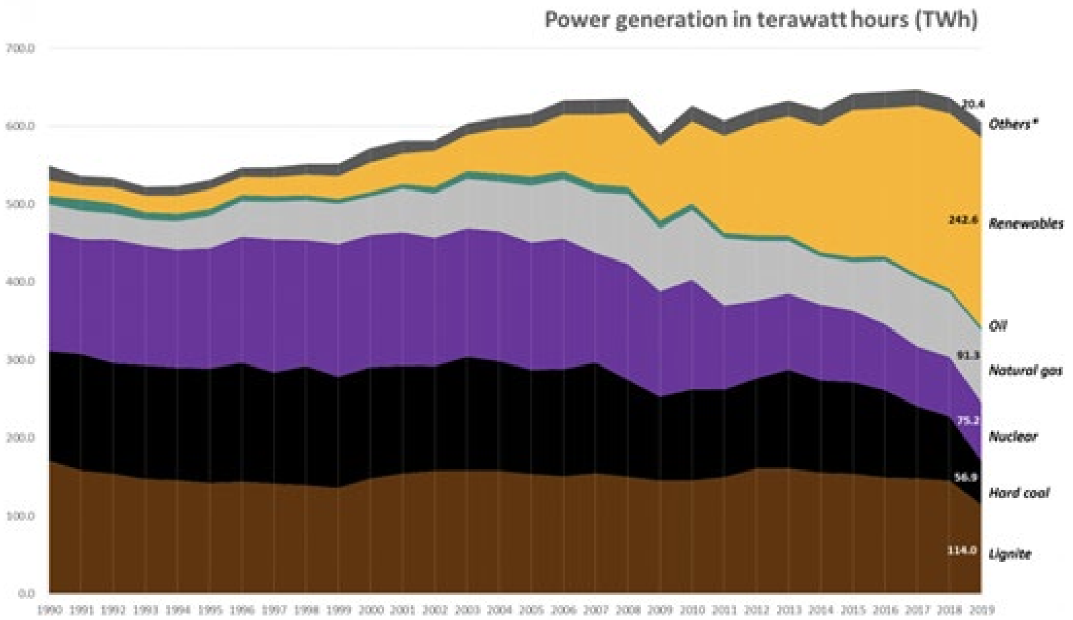



*Figure 3 German gross electricity production by source 1990 to 2019 (Clean Energy Wire, 2020)*

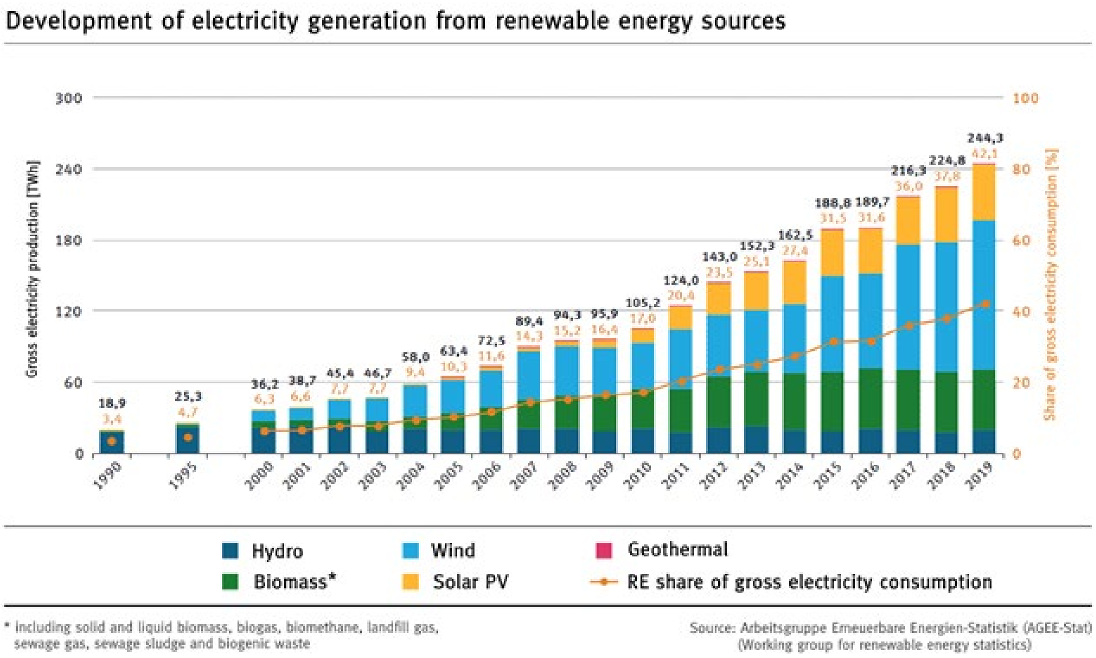



*Figure 4 Development of electricity generation from renewable energy sources since 1990 (Umweltbundesamt, 2020) (translated)*

### Targets and predictions

Germany must reach 80 % renewable energy in electricity generation by 2050 to comply with greenhouse gas reduction target of 80-95 % from 1990 to 2050 (50Hertz Transmission GmbH et al., 2020).

The German Council of Environmental Advisors (Sachverständigenrat für Umweltfragen, SRU) was one of the first to analyze a scenario with 100 % renewable electricity in 2050. The German electricity load can be met in every hour of the year with 100 % renewable energy – even if the generation is based on the highly fluctuating sources, wind and solar, and even if Germany is totally isolated from the rest of Europe (SRU, 2011). The development of the German generation mix in the SRU scenario is shown in Figure 5. The SRU relied mainly on offshore wind energy, as it was skeptical of the long-term acceptance of a large increase of onshore wind energy capacities and the contribution of solar energy to the German electricity generation in the winter.

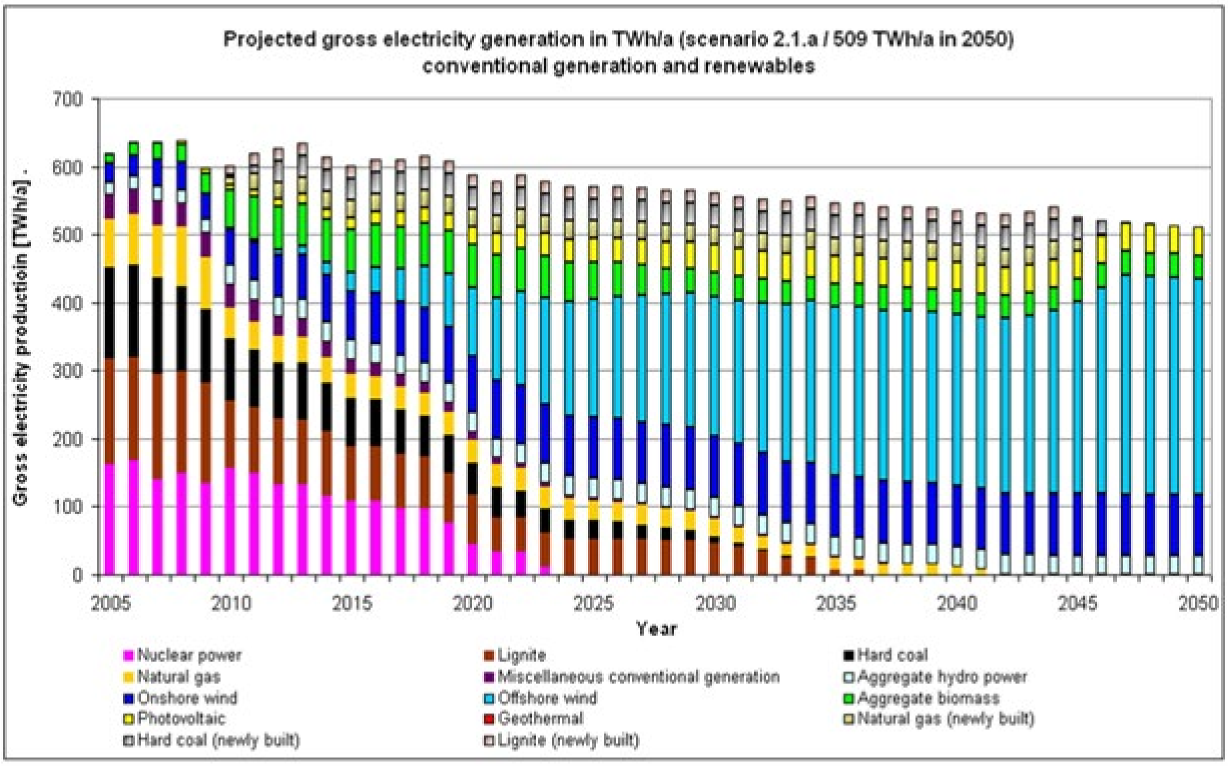



*Figure 5 Projected development of gross electricity generation in Germany until 2050 in the core scenario of the German Council of Environmental Advisors (SRU, 2011)*

## The German electricity grid in 2019

Germany has a highly developed and reliable electricity grid, which is an integral part of the European high voltage electrical grid infrastructure. It has functioned reliably for decades with a minimal number of outages and a stable frequency. The total outage time in Germany and Denmark are less than 25 % of the EU average (European Commission, 2018).

The German high voltage grid must be extended and reinforced to absorb the bulk of the German renewable energy generation. It has been built to transfer electricity from large central thermal power plants (coal, gas, oil and nuclear) built strategically close to load centers. All studies and plans concerning the future of the German electricity agree that wind energy will be the key renewable energy resource. The best wind resources in Germany are located offshore in the North and Baltic Sea or on shore in Northern Germany. The high voltage grid must be extended and reinforced to transmit wind energy produced in the North to the load centers in West and South Germany. Accordingly, the network map in Figure 6 shows numerous high voltage power lines under construction and in the planning phase, improving both transportation from Northern to Southern Germany as well as across country borders. Figure 10 shows the specifics of the grid in Schleswig-Holsten, the region in which the DG STORE project takes place.


*Figure 6 The planned expansions and reinforcements of the German high voltage power grid (200 kV+) (Alexrk2, 2013) (translated)*

# SCHLESWIG-HOLSTEIN'S ENERGY SYSTEM OVERVIEW

The focus of the DG STORE project is the Flensburg area, which is located in Schleswig-Holstein, one of sixteen federal states in Germany. Schleswig-Holsten is home to 3.5 % of the German population (Wikipedia, 2020) and large capacities of renewable energy sources, mainly wind. In 2016, the state produced almost 130 % of its gross electricity consumption, and 30 % of its entire energy consumption, from renewable energy sources (see Figure 7).

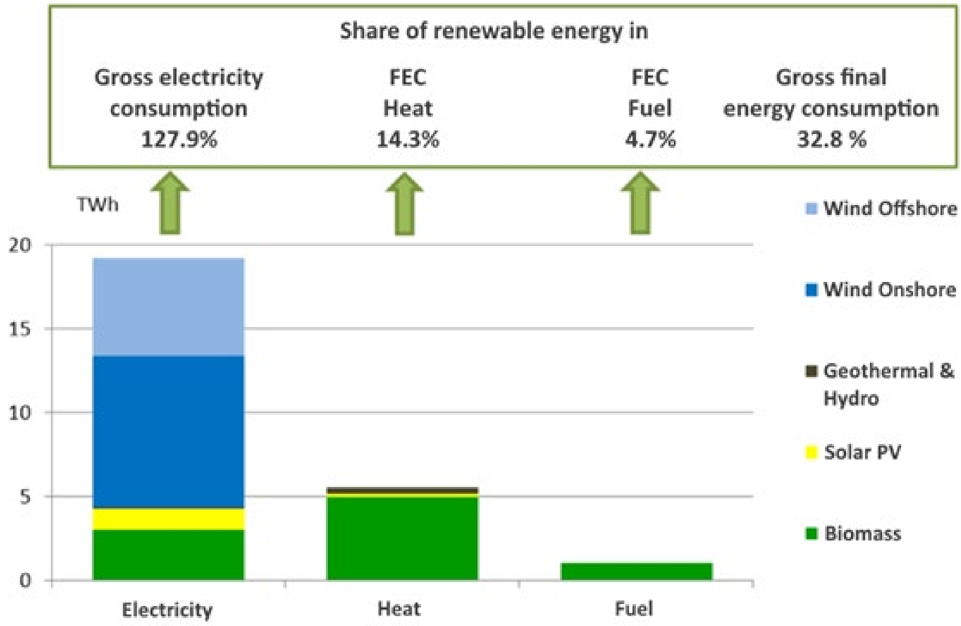



*Figure 7 The shares of renewable energy sources in the final energy consumption for electricity, heat and fuels of Schleswig-Holsten by sector in 2016 (Landesregierung Schleswig-Holstein, 2018) (translated)*

## Electricity generation and consumption in Schleswig-Holstein

Schleswig-Holsten has historically operated a large nuclear capacity. With only one remaining power plant after the shutdown of two others, 11 % of the installed capacity was nuclear power in 2019. The last remaining nuclear power plant is due to be shut down in 2021.

The electricity produced from renewable sources has reached 55 % of the total gross electricity production as seen in Figure 8. The production is dominated by wind, both onshore and offshore. After 2012 the biogas development stalled due to an increasing public debate on the competition between energy crops and food production.

By 2025, Schleswig-Holstein aims to supply 200-250 % of its gross electricity consumption from renewable sources. This would cover more than 100 % of the join electricity demand of Schleswig-Holstein and the city of Hamburg, the next largest load center (see Figure 9). As Hamburg has hardly any space for renewable power production besides rooftop PV, it is foreseen that Hamburg will produce very little RE-based electricity.

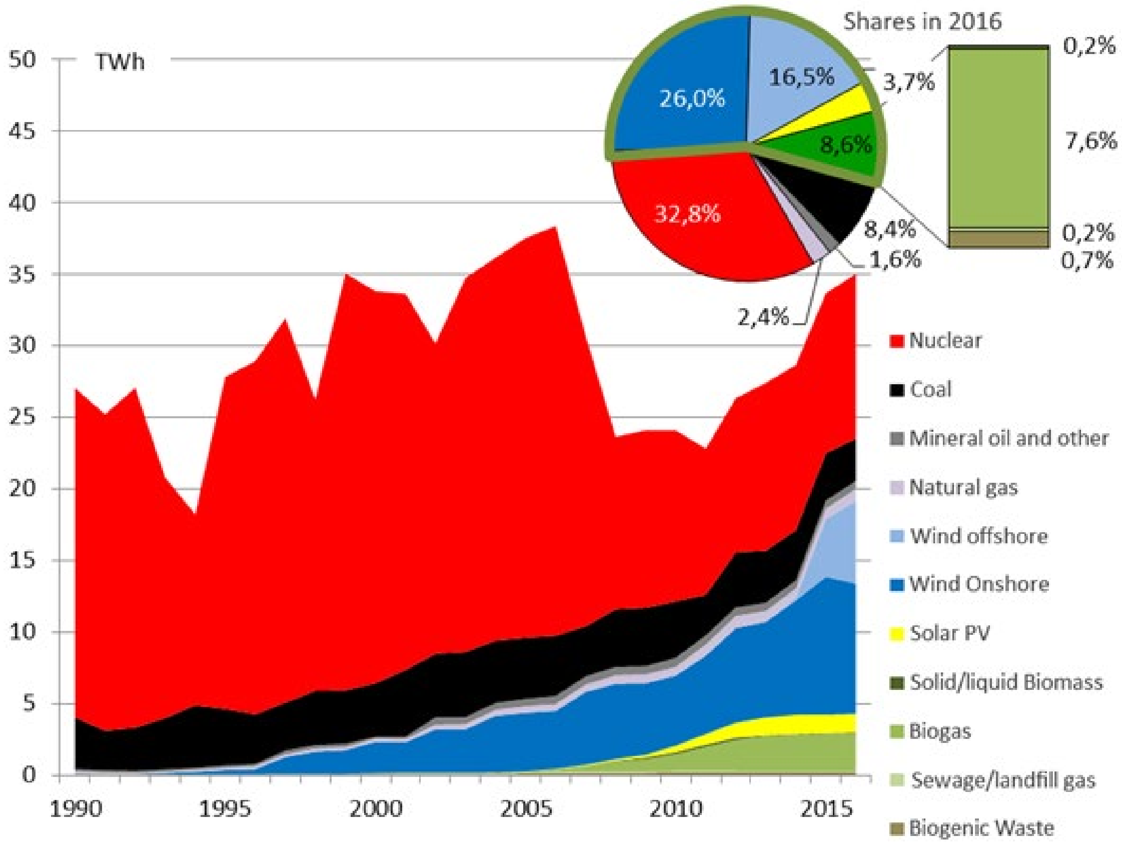



*Figure 8 Gross electricity generation in Schleswig-Holstein from 1990 to 2016 by source (Landesregierung Schleswig-Holstein, 2018) (translated)*

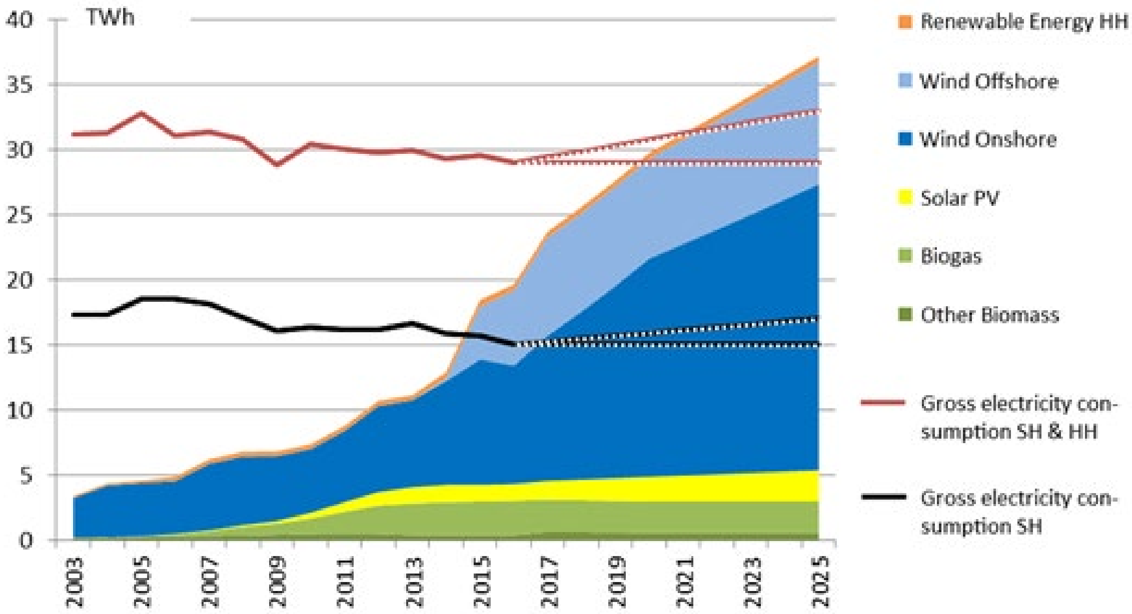



*Figure 9 Electricity production from renewable energy sources and gross electricity consumption in Schleswig-Holstein (SH) and Hamburg (HH) from 2003 to 2025 (planned) (Landesregierung Schleswig-Holstein, 2018) (translated)*

## The high voltage grid in Schleswig-Holstein

The transmission grid in Schleswig-Holstein has historically served two purposes: Connecting the German and Nordic grids and exporting electricity from large generators, e.g. nuclear power plants, to the rest of Germany.

To improve transmission capacities for electricity generated from increasing renewable energy-based power production, the high voltage grid must be expanded and enhanced. The planned expansion is shown in Figure 10. One of the planned expansions is NordLink: A direct connection to the large hydropower system at Tonstad, Norway, with a capacity of 1.4 GW transmission capacity. This allows using the Norwegian hydropower system as indirect storage for the overproduction of wind energy and to remedy bottlenecks in the German high voltage power lines south of Hamburg.


*Figure 10 The present and planned high voltage grid in Schleswig-Holstein (Landesregierung Schleswig-Holstein, 2018) (translated)*

# FLENSBURG'S ENERGY SYSTEM OVERVIEW

On the German side, the DG STORE project focuses on the supply area of Stadtwerke Flensburg, which directly supplies Flensburg, Glücksburg and Harrislee, three interconnected municipalities. This combined supply area has a size of 115 km2 and a population of approx. 105,000 as of 2015 (Wikipedia, 2020).

## District Heating

Stadtwerke Flensburg participates in case 1 of the DG STORE project concerning electrification of the district heating system. This has great potential, as Stadtwerke Flensburg is the most successful supplier of district heating in Germany with a 98 % coverage of its supply area. The generation capacities are shown in Figure 11.

Figure 12 shows the development of heat produced and supplied by Stadtwerke Flensburg. The demand is expected to decline long-term due to improved insulation of buildings.

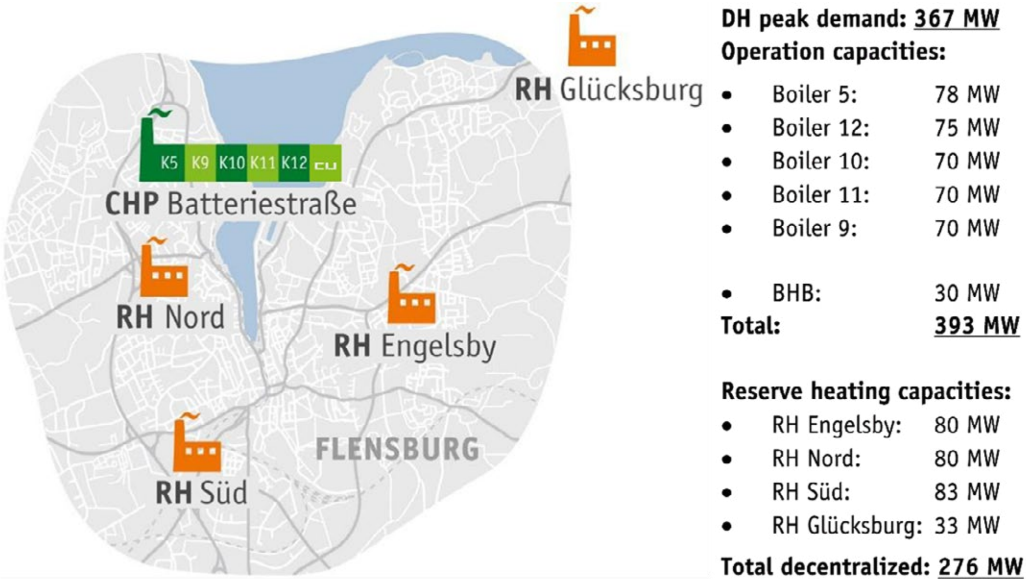



*Figure 11 District heating generation capacities of Stadtwerke Flensburg. DH: District heating, CHP: Combined heat and power plant, RH: Reserve heating plant, BHB: Backup heating boiler (Stadtwerke Flensburg, 2019) (translated)*

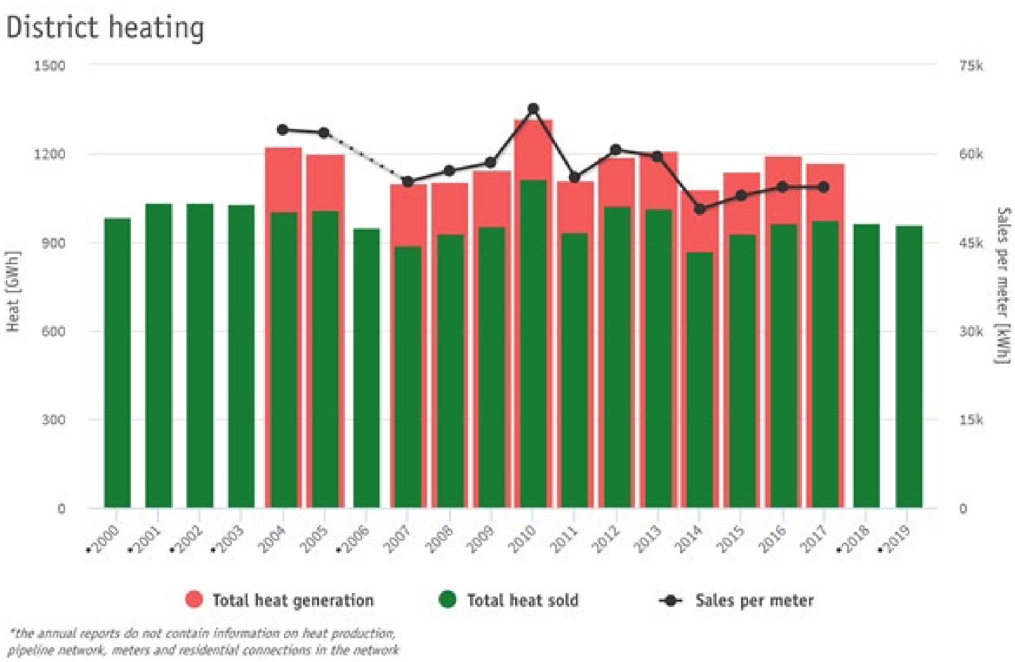



*Figure 12 Annual district heating production and supply of Stadtwerke Flensburg from 2000 to 2019 (Stadtwerke Flensburg, 2020b) (translated)*

## Electricity

Stadtwerke Flensburg is both a generator and trader of electricity. While sales in its own supply area have dropped in the past decade, total sales of electricity have increased as seen in Figure 13.

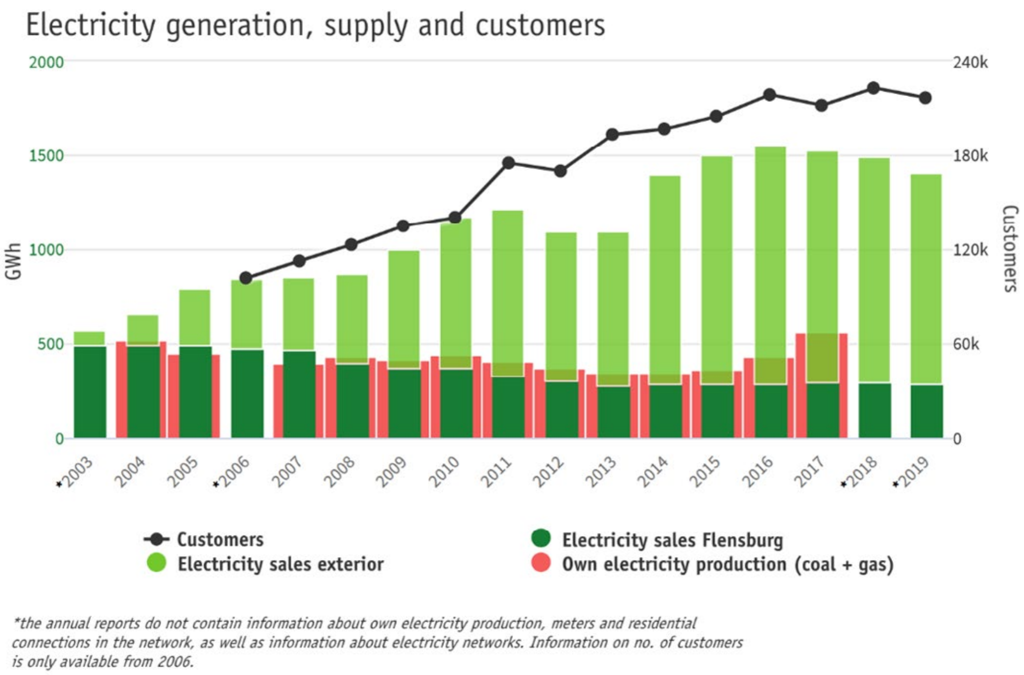



*Figure 13 Electricity generated and sold by Stadtwerke Flensburg between 2003 and 2019 (Stadtwerke Flensburg, 2020b) (translated)*

The electricity is mainly distributed through a 60 kV cable ring (Figure 14), which is connected to the power plant at the harbor, the German high voltage grid and to the Danish grid.


*Figure 14 The supply area of Stadtwerke Flensburg, the 60 kV cable ring system and the connections to the German and Danish high voltage grid (Stadtwerke Flensburg, 2020a) (translated)*

# DENMARK'S ENERGY SYSTEM

## Denmark's Energy Consumption

Denmark is known for high levels of renewable energy, especially wind power. In 2018, approx. 33 % of the country's energy production came from renewable energy sources as seen in Figure 15. Biomass and wind are the most important sources of renewable energy (see Figure 16).

In 2030, 55 % of the energy consumption must be covered by renewable sources (Klima- Energi- og Forsyningsministeriet, 2018). Denmark must be entirely greenhouse gas-neutral in 2050, e.g. emit no more greenhouse gases than can be taken up (Energistyrelsen, 2020c).

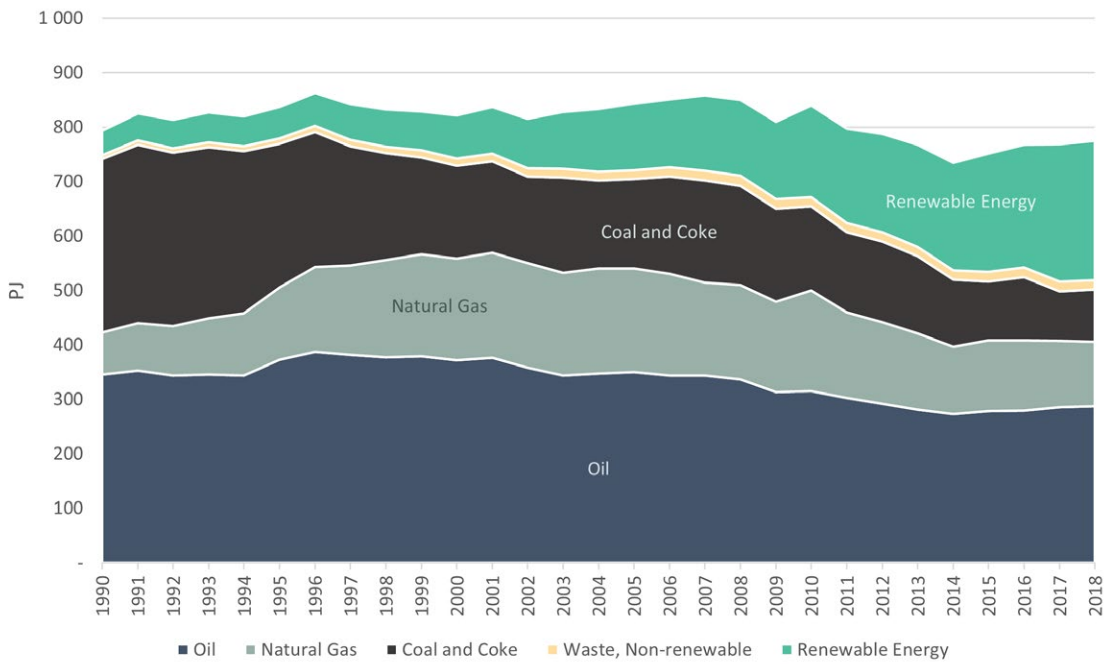



*Figure 15 Denmark's Gross Energy Consumption, 1990-1991. Data from the Danish Energy Agency's Energy Statistics 2018 (Energistyrelsen, 2019)*

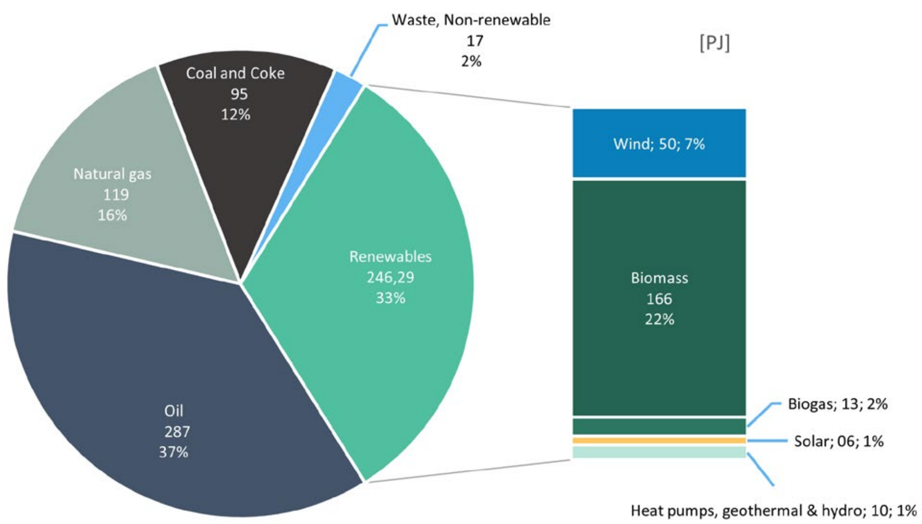



*Figure 16 Denmark's gross energy consumption in 2018 by fuel in PJ and percentage of total consumption. Data from the Danish Energy Agency's Energy Statistics 2018 (Energistyrelsen, 2019)*

## Denmark's Electricity System

**The Danish electricity system historically**

Denmark has been, and is still, expanding renewable energy production. The expansion shows most clearly in the electricity generation, which is shown in Figure 17. Wind power and biomass are the primary sources of renewable energy in the electricity generation.

The expansion of biofuels can be problematic, as biomass is a very valuable but also limited resource. Therefore, the usage of power sources such as wind, solar and hydro power, which have no direct greenhouse gas-emissions, is key to a climate-neutral society. When the electricity supply becomes more and more dependent on fluctuating energy sources, and supply and demand often do not match, new ways to balance the electricity grid are required. DG STORE aims to investigate how electricity from wind and solar power can be used in the heating and transportation sectors, and how that can help balance the electricity grid.

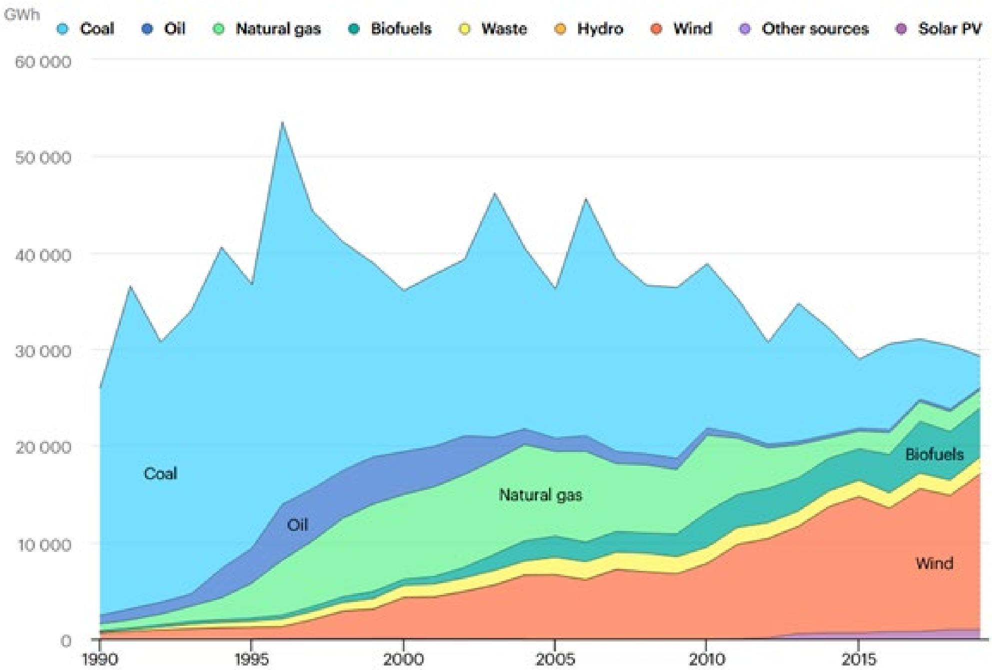



*Figure 17 Electricity generation by source, Denmark, 1990-2019 (IEA, 2019)*

Figure 18 shows Denmark's electricity supply by source. In comparison to Figure 17, this includes import of e.g. hydro- and nuclear power from neighboring counties, and excludes electricity exports, thereby showing the sources of electricity bought by Danish consumers.

The supply of electricity comprised of 45 % wind power and 4 % solar power in 2019 (see Figure 18). Despite the challenges posed by such a high volume of fluctuating energy sources, the electricity security is one of the highest in Europe at a 99.996 % supply rate in 2019 (Energinet, 2020g).

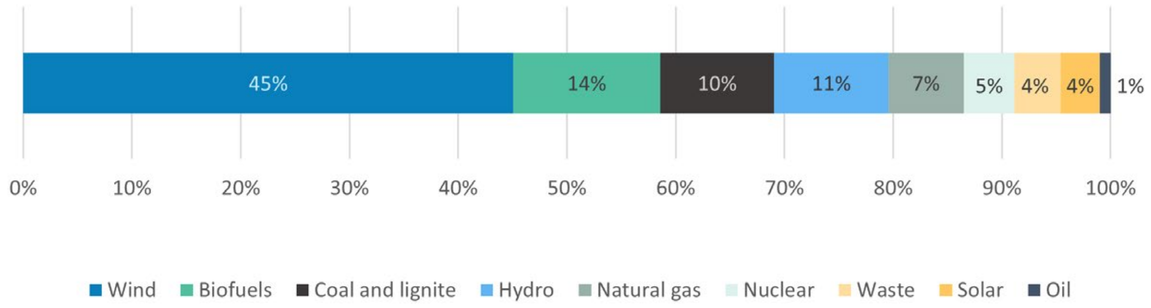



*Figure 18 Electricity consumption by source in Denmark, 2019. Data from Energinet's Miljødeklaration (Energinet, 2020e)*

The electricity and heating sectors are closely interconnected. As Figure 19 shows, most power plants in the country are Combined Heat and Power (CHP) plants, which, as the name suggests, produce heat and power simultaneously. In 2018, 71% of thermal electricity production (i.e. total production excl. wind, solar and hydropower) was produced in CHP plants. 64 % of Danish households are supplied with district heating, which is often produced by a CHP plant (Dansk Fjernvarme, 2020).

In Denmark, waste incineration is very common. The waste can be used as fuel in CHP or pure heating plants, and 21 % of all district heating was supplied by waste in 2018 (Energistyrelsen, 2019).

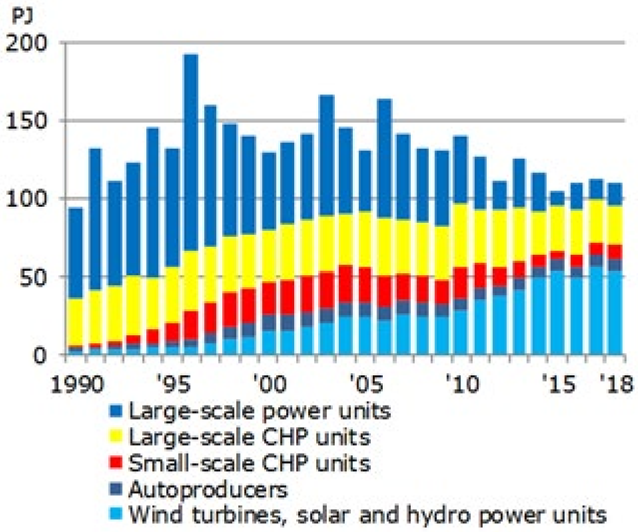



*Figure 19 Electricity production by type of producer, 1990-2018 (Energistyrelsen, 2019)*

Figure 20 shows all large Danish electricity producers as well as the high-voltage transmission grid. The transmission grid is managed and owned by Energinet, and transports electricity from power plants, wind turbines and solar plants to the local distribution grids. It is divided into two parts; DK1, which covers the Jutland and Funen areas, and DK2, covering Zealand and the surrounding islands. The 600 MW DC-cable between Funen and Zealand connects these two areas.

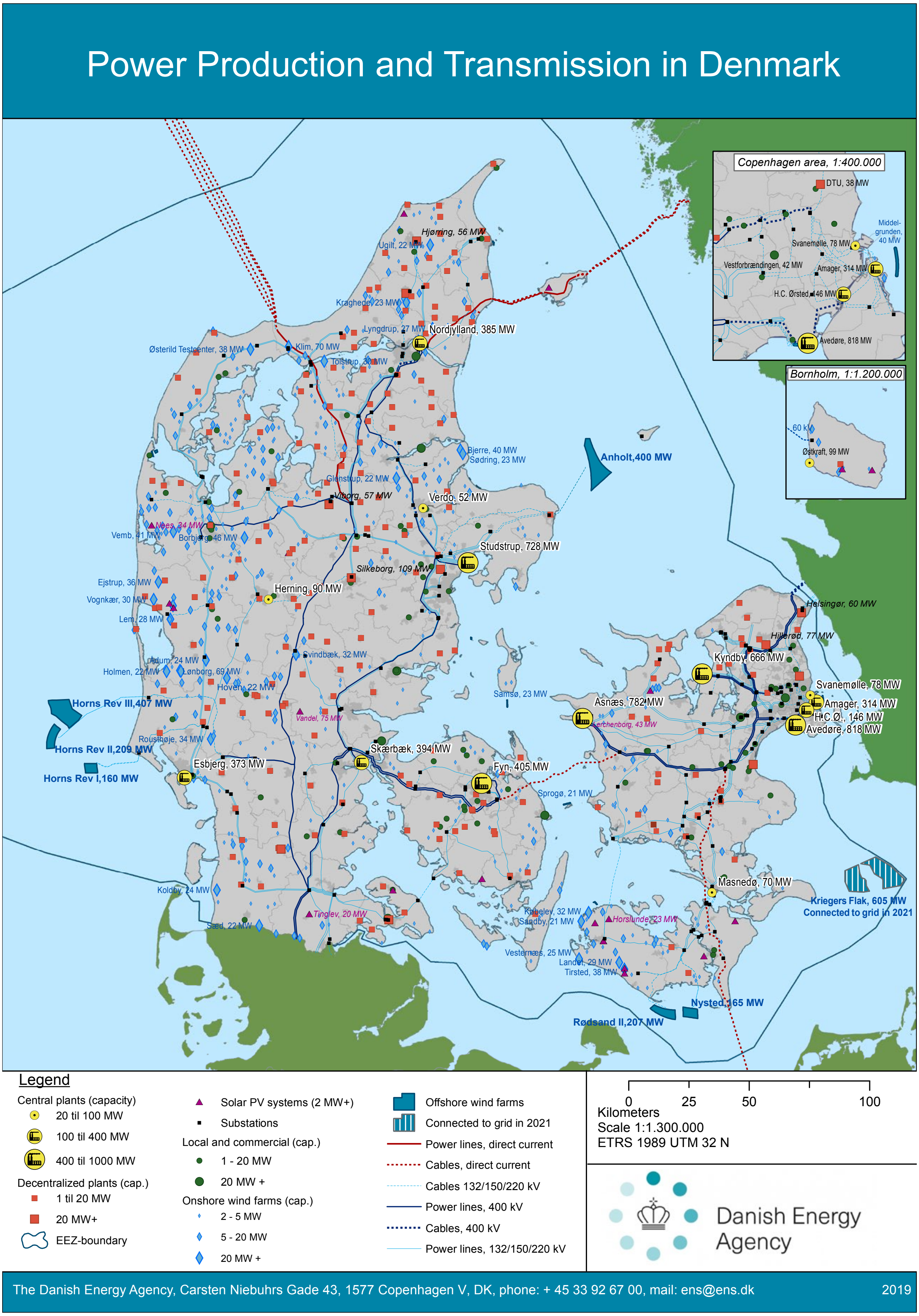



*Figure 20 Power Production and Transmission in Denmark (Energistyrelsen, 2020d)*

## Targets and predictions

The Danish Climate Law states that Denmark must be climate neutral in 2050 as well as reduce greenhouse gas emissions by 70 % from 1990 to 2030.

By 2030, 100 % of the electricity is to be covered by renewable energy sources (Klima- Energi- og Forsyningsministeriet, 2018). The Danish Energy Agency expects that this goal will be reached in 2027, in large parts due to increased wind and solar production capacities (Energistyrelsen, 2020b). As seen in Figure 21, the electricity sector has a predicted 111 % share of renewable energy in 2030.

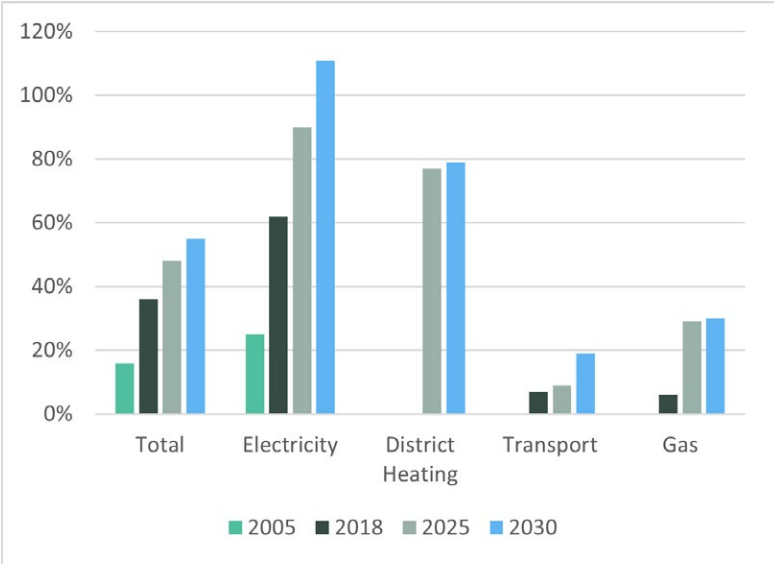



*Figure 21 Renewable energy shares in different parts of the energy sector in 2005 and 2018 and predictions for 2025 and 2030. Data from Basisfremskrivning 2020 (Energistyrelsen, 2020b)*

A large part of the increased electricity production stems from wind and solar power (see Figure 22). The Danish production of wind and solar power exceeds electricity demand from 2029 even though demand continues to increase. As seen in Figure 23, classic electricity consumption increases very slightly. Within the next 20 years, the largest part of the Danish electricity consumption will come from new forms of consumption: Power-to-X, transportation, large data centers and heat pumps.

This shows that the DG STORE showcases in transportation (cases 3, 4 and 7) and heating (cases 1 and 5) will become increasingly relevant in a future electricity system.

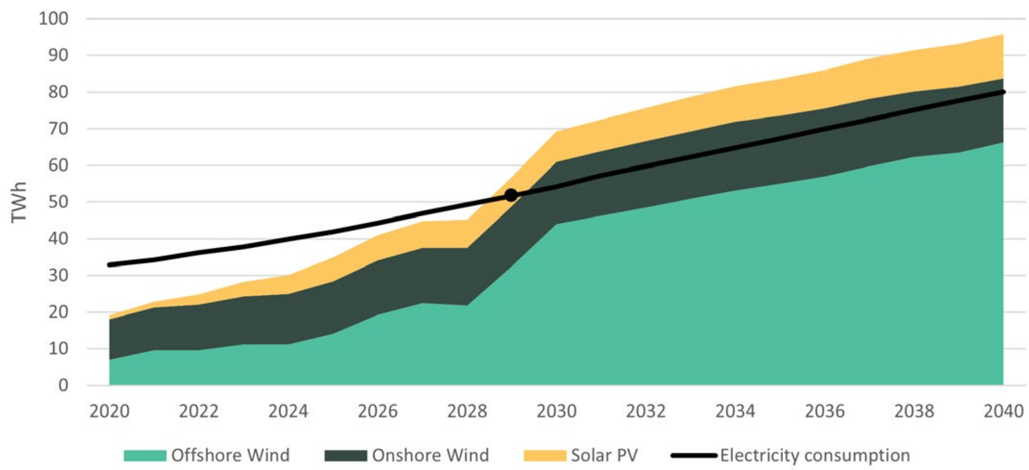



*Figure 22 Production of wind- and solar power along with total electricity consumption [TWh] in Denmark 2020-2040. Prediction from the Danish Energy Agency's Analyseforudsætninger (Energistyrelsen, 2020a)*

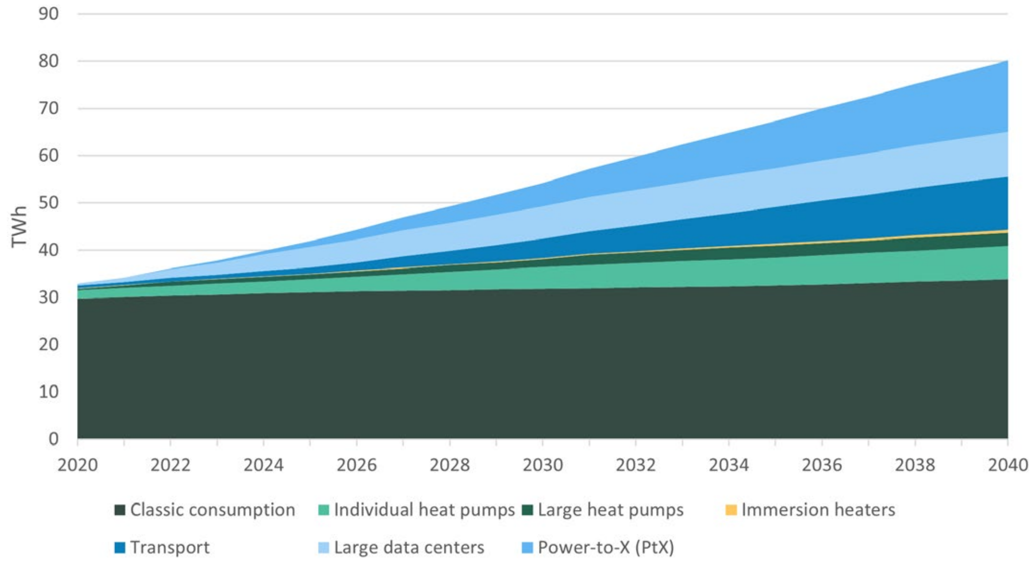



*Figure 23 Consumption of electricity in Denmark [TWh] 2020-2040 by usage. Prediction from the Danish Energy Agency's Analyseforudsætninger (Energistyrelsen, 2020a)*

# LOLLAND'S ENERGY SYSTEM

Lolland is a Danish Island located south west of Zealand, and is, along with Flensburg, the focus of the DG STORE project. The population density is low, leaving space for expansion of renewable energy generation (especially wind and solar power), while there are only few large power consumers (mainly sugar production).


*Figure 24 Electricity Distribution System Operators (DSOs) and Municipalities on Lolland*

DG STORE focuses on testing, applying and analyzing flexibility and storage technology in Lolland Municipality, which is the westernmost part of the island along with the smaller surrounding islands. This area is shown in Figure 24. The figure also shows the Distribution System Operators (DSOs) in the area. Cerius is the primary DSO, but Nakskov Elnet A/S, a part of Lolland Forsyning A/S (Lolland utility company), manages the electricity grid in the city of Nakskov.

In 2019, Lolland Municipality's renewable electricity production was nine times its consumption. If offshore wind turbines are disregarded, Lolland still produced 3-4 times its consumption that year from solar and wind power. Figure 25 shows the production and consumption in the municipality in 2019.

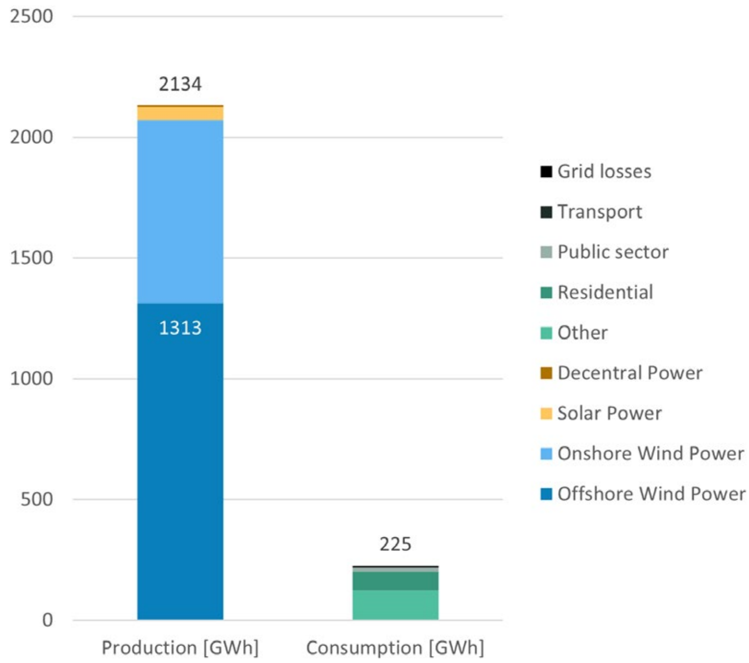



*Figure 25 Electricity Production and Consumption in Lolland Municipality 2019. Data from Energidataservice.dk (Energinet, 2020b)*

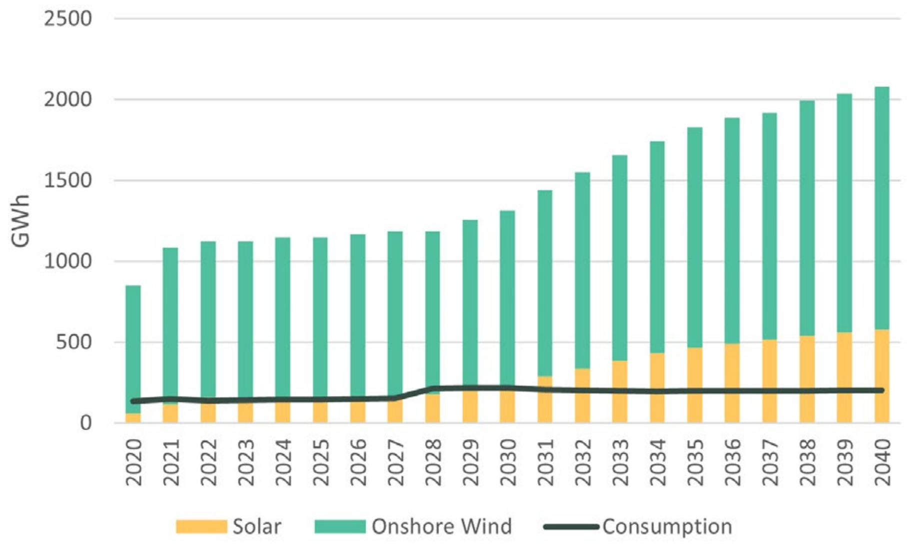



*Figure 26 Prediction of electricity production from solar and onshore wind as well as electricity consumption in Lolland Municipality, 2020-2040[1]. Data from Energinet's Kapacitetskort (Energinet, 2020d) and Technology Data (Energistyrelsen, 2020f)*

Figure 26 shows an approximate prediction of electricity production from onshore wind and solar power compared to the predicted electricity consumption in Lolland Municipality. Compared to Figure 22 showing all of Denmark, the large difference in production and consumption is striking. An increase in new plants as well as repowering of older, smaller plants, means that the production to consumption ratio will continue to increase in the coming years. Because of this, more and more electricity must be transported to other areas.

This shows that the issues tackled in the DG STORE project are not limited to just one municipality. The flow of electricity and heat might cross municipal, regional or even national borders. As seen in Figure 27 and Figure 28, overloads in the electricity grid connected to Lolland will occur in the near future. When production of wind and solar power continues to increase, the demand for transportation might exceed the capacities in the electricity grid. If no other solutions are implemented, the production will have to be stopped when the capacity in the electricity grid does not allow for transport.

In order to continue the growth of renewable energy, especially on Lolland, it is necessary to implement energy storage solutions and flexible consumption, so more of the production can be consumed locally.

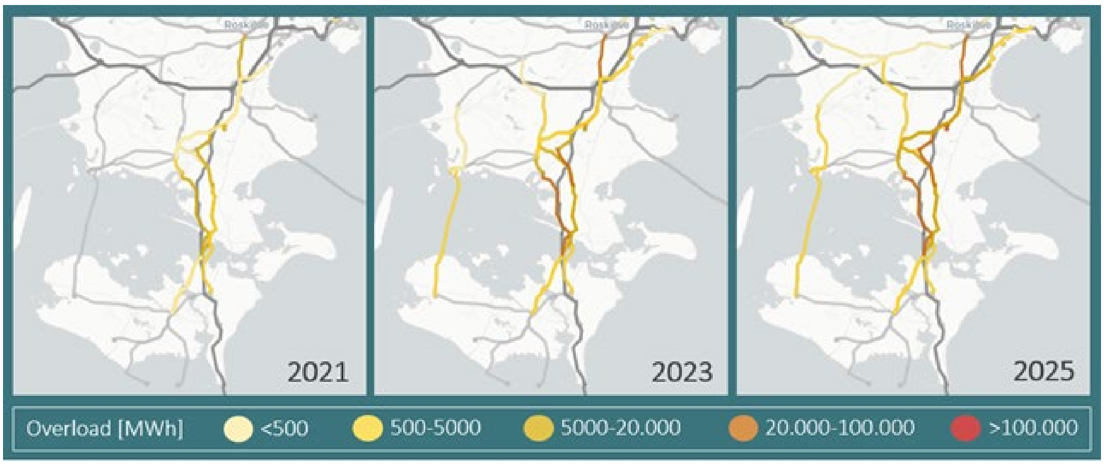



*Figure 27 Overload energy per year in an N-1 scenario[2] for 2021, 2023 and 2025 on Lolland-Falster and Southern Zealand from Energinet's Behovsanalyse for Eltransmissionsnettet 2020 (Energinet, 2020a)*

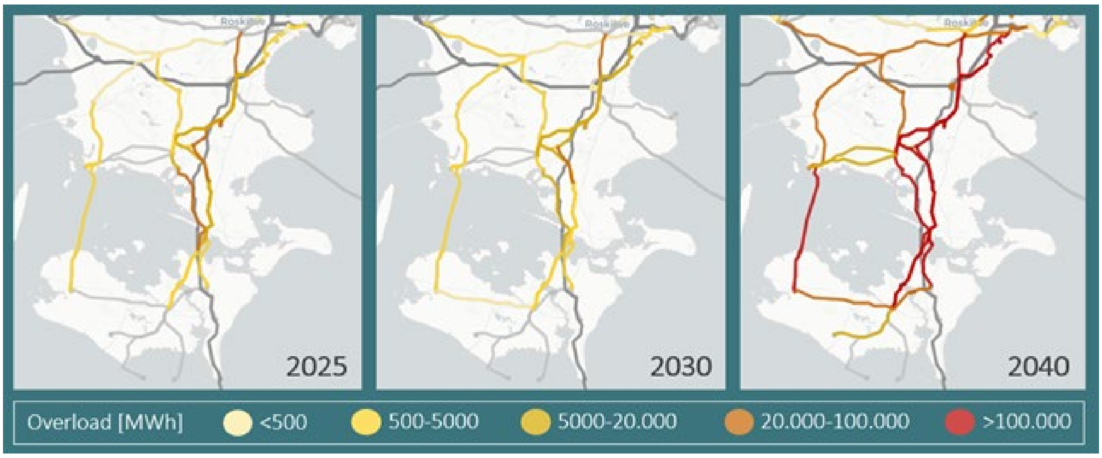



*Figure 28 Overload energy per year in an N-1 scenario2 for 2025, 2030 and 2040 from Energinet's Behovsanalyse for Eltransmissionsnettet 2020 (Energinet, 2020a)*

## Sector Coupling

**Heat Supply**

Net heat demand in in Lolland Municipality was approx. 660 GWh in 2018. Almost 30 % of the net heat demand was supplied by oil heaters as seen in Figure 29. The phasing-out of oil heaters is an important element in the Danish government's climate agreement from June 2020 (Klima- Energi- og Forsyningsministeriet, 2020). Part of the capacity can be replaced by expanding the areas of district heating. The remaining represents a potential expansion of single or collective heat pump systems, or other heating systems based on electricity from the increasing RE-generation.

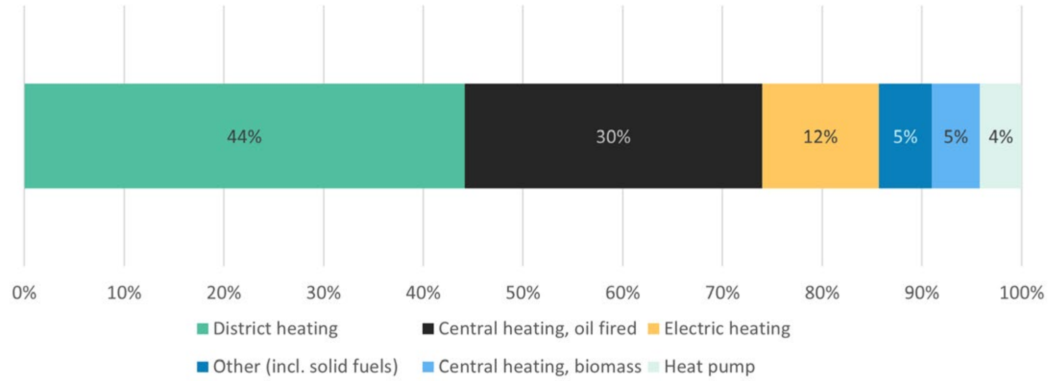



*Figure 29 Net heat demand by source, Lolland Municipality 2018. Data from Varmedata Lolland Kommune (Gaarsmand and Kjær, 2018)*

In Figure 30, actors of the heating sector in Lolland Municipality are shown. Most consumers, especially in the cities, are supplied by district heating. The district heating companies in the municipality are shown in the figure, and cover each of the green areas on the map. The remaining consumers use oil burners, furnaces, electric heaters or heat pumps for heating. In many other parts of Denmark, the heat supply is from household gas-fired boilers, but in Lolland there is no gas grid.

The largest supplier of district heating in Lolland Municipality is Lolland Varme A/S (Lolland district heating company), which delivers district heating in both Nakskov, Søllested and other smaller villages. Lolland Varme A/S is a part of Lolland Forsyning A/S, which also manages Nakskov Elnet (see Figure 24).

Lolland Municipality's heat supply is connected to that of the neighboring municipality, Guldborgsund. Maribo-Sakskøbing CHP-plant, managed by REFA, delivers 75 % of the heat supplied by Maribo Heating plant. REFA also manages Holeby District heating and facilitates purchases of biomass for the heating plants in Lolland Municipality.

DG STORE examines the potential of flexible power consumption in district heating plants in showcase 1 at Lolland Heating and Flensburg Utility. Case 2 works with flexible heating and cooling at supermarkets and case 5 demonstrates the flexibility potential of heat pumps with thermal storage at larger public buildings.

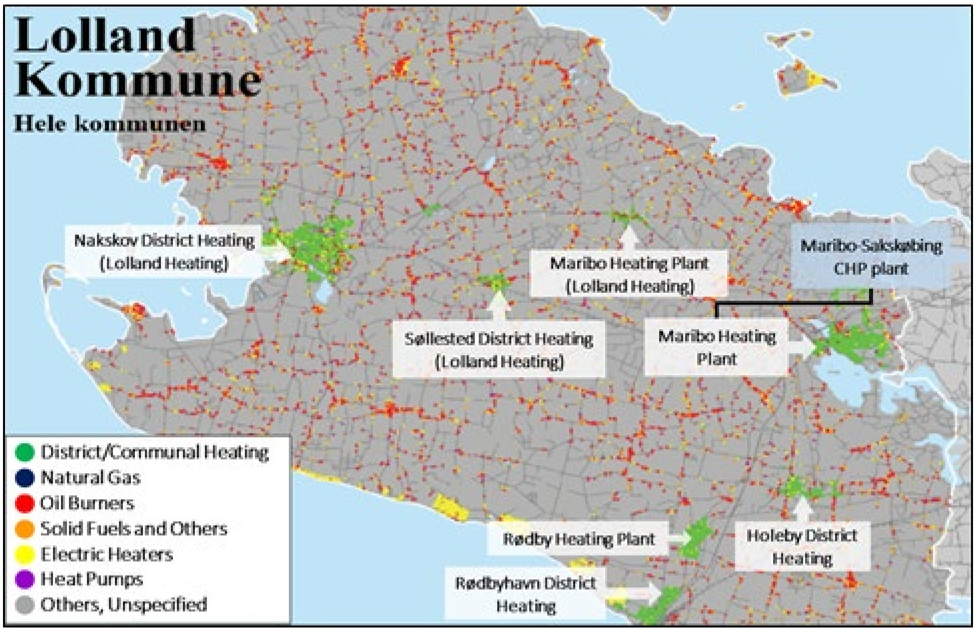



*Figure 30 Lolland Municipality: Actors of the Heating Sector (Gaarsmand and Kjær, 2018) (Stokkemarke Lokalblad, 2019)*

**Transportation**

Lolland Municipality currently has one of the lowest shares of EVs in Denmark, so the potential for a larger coupling between the electricity sector and the transportation is great. In January of 2020, there were only 37 electric and 34 hybrid passenger vehicles owned by residents and businesses of Lolland Municipality. To reach the national goal of a 70 % GHG-reduction in 2030, 38 % of cars would need to be electric. With an even distribution around the country, the Lolland-Falster area would need 192 times more electric in 2030 (Danmarks Statistik, 2020). One of the main efforts needed to make this happen is more and better charging infrastructure (Ea Energianalyse, 2020).

The 40,800 people in Lolland Municipality will consume an additional 30 GWh of electricity each year if 38 % of the fleet is to be electrified[3]. That corresponds to 13 % of the total 2019 electricity consumption. This number could be even higher, as residents in rural areas – like Lolland Municipality – tend to drive longer distances than the average Dane. This number only accounts for personal vehicles: Public transportation and heavy road transportation have a large electrification potential. In 2021, electric busses will become a part of Lolland Municipality's public transportation. By 2030, all buses by the local public transport provider (Movia) will be fossil-free, and at least half will be electric in 2030 (Kollektiv Trafik Forum, 2020).

A larger EV fleet will be able to provide flexibility in electricity consumption. Few EV owners need their vehicle to charge the moment they plug it in, and smart control based on current electricity production and weather-based production prognosis can help stabilize the grid. This can also be of benefit to consumers, who can save money by charging when the supply of electricity exceeds the demand. DG STORE looks at electric vehicles and buses as flexibility providers in cases 3, 4 and 7.

# INTERCONNECTIONS AND ELECTRICITY TRADE

Denmark and Germany have strongly interconnected electricity systems. Figure 31 shows capacities of the electric connections between Denmark and Germany. The connections from Jutland to Germany will be expanded in the coming years, increasing the capacity to 3500 MW. In eastern Denmark, a transmission line through a new off-shore wind farm, Kriegers Flak, will establish another connection between Germany and Zealand, which will start operating in late 2020 or early (Energistyrelsen, 2020a). As of now, mid-December 2020, the line is being tested. The development can be followed on Energinet.dk.

In 2018, the TSOs TenneT and Energinet signed a Joint Declaration to secure minimum transfer capacities across the Danish/German border, which will increase as new transmission capacity is introduced.

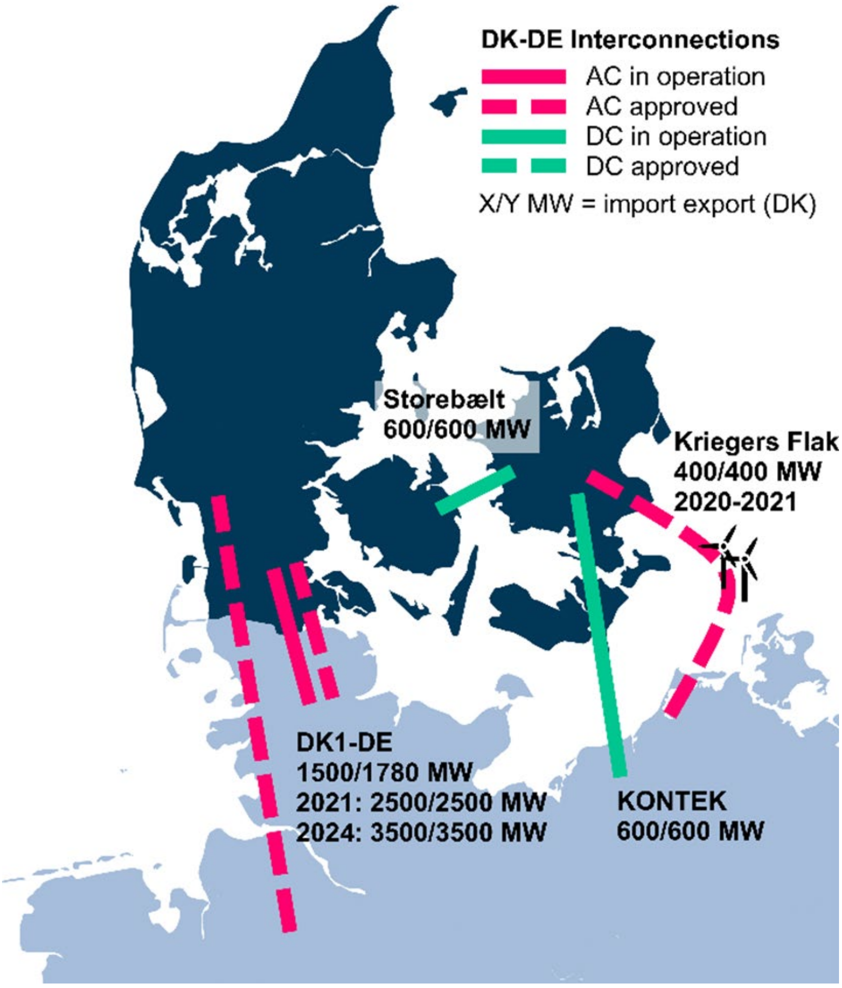



*Figure 31 Electrical Transmission Connections between Denmark and Germany: Current (2020) and approved connections. Data from AF20 (Energistyrelsen, 2020a)*

Both Denmark and Germany trade electricity with a range of neighboring countries.

Nordic and Baltic countries, including Denmark, trade power through Nord Pool on a day-ahead and intra-day market. DK1 is connected to Norway, Sweden, Germany and the Netherlands, whereas DK2 is connected to Sweden and Germany. The Viking Link-connection between DK1 and Great Britain is due to start operating in 2023 (Energinet, 2020c).

Nord Pool price trends are significantly influenced by varying precipitation patterns in Norway and Sweden, whose electricity production is dominated by hydropower. These price variations strongly affect Denmark's foreign trade, shown in Figure 32.

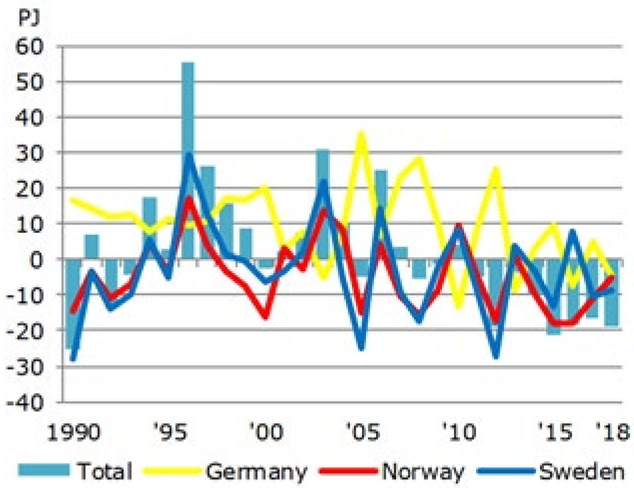



*Figure 32 Danish net exports of electricity by country, 1990-2018 (Energistyrelsen, 2019)*

Although Germany phased out substantial conventional power plan capacities – especially after the Fukushima nuclear accident in 2011 – it did not become a net importer of electricity, as many critics of the nuclear phase-out claimed. Due to an increasing share of renewable electricity, the net export has increased substantially in the last ten years as can be seen from Figure 33.

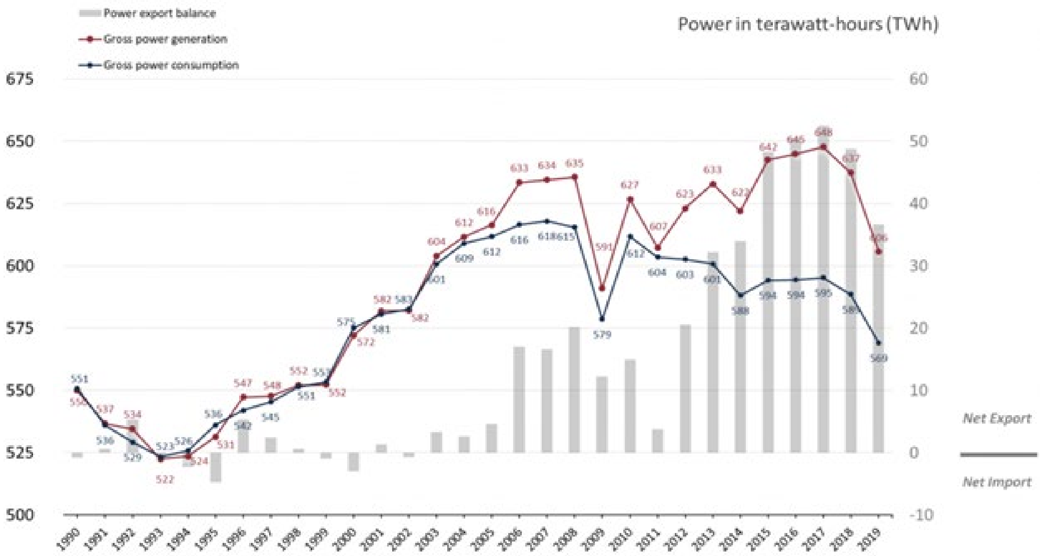



*Figure 33 German power export balance 1990-2019 (Clean Energy Wire, 2020)*

# THE NEED FOR STORAGE AND DSM

Any electricity system relying on high shares of wind and solar energy will need high volumes of short term and seasonal storage to solve long- and short-term problems. This is the case in both Denmark and Germany, and especially in the Flensburg and Lolland areas.

## Storage and Demand Side Management (DSM)

Storage can take different forms, as long as it allows shifting energy produced across time. Figure 34 shows the principal use of storage and DSM to minimize the mismatch between generation and demand. The DG STORE project focuses on indirect storage: Flexible energy consumption in the heating and cooling in retail (case 2), in charging of electric vehicles (cases 3, 4 and 7) and in heating in individual buildings (case 5). This is also known as demand side management (DSM), as the consumers adapt to the behavior of the producers.

In all the project's showcases, the energy service delivered is not impacted by the time shift of the energy demand. The temperature of a room or a freezer is not significantly impacted by shifting the heating/cooling by a short amount of time, and the driver of a car does not care when the car charges, as long as it is charged sufficiently once the driver needs it.

Storage and DSM can solve problems with discrepancies in space and time. The space-discrepancies occur when production does not happen in the same place as the consumption, and the transmission grid does not have the capacity to transport the surplus electricity to load centers. Discrepancies in time happen when the electricity production and consumption do not happen at the same time. A high volume of renewable, fluctuating electricity production creates both problems. When most of the electricity is produced in areas with high wind and solar potentials, the need for national and international transportation increases. Both Denmark and Germany are working on improving the capacities and extends of the electricity grid. While working on this expansion, there is a problem with discrepancies in space that need to be solved with local storage options in the areas of high production.

While the problems with discrepancies in space are temporary, electricity production from wind and solar perfectly will never perfectly match demand in time. For the electricity grids to function, production and consumption must always match. This time-discrepancy creates a long-term demand for storage and DSM as soon as the production of electricity is (temporarily) higher than the consumption.

The Danish electricity supply is predicted to be 100 % renewable in 2027 (Energistyrelsen, 2020b), creating a need for time-shifting storage and DSM. This will predate the extension and expansion of the electricity grid needed to eliminate space-shifting needs, meaning that the market for storage and DSM in Denmark is continuous.

For Germany, a scenario with 100 % renewable electricity production is likely to occur after a sufficient expansion of the electricity grid has eliminated problems with space-discrepancies between production and consumption of electricity. The market for storage and DSM in Germany is temporary but will re-appear as the share of renewable energy in the electricity production gets closer to 100 %.

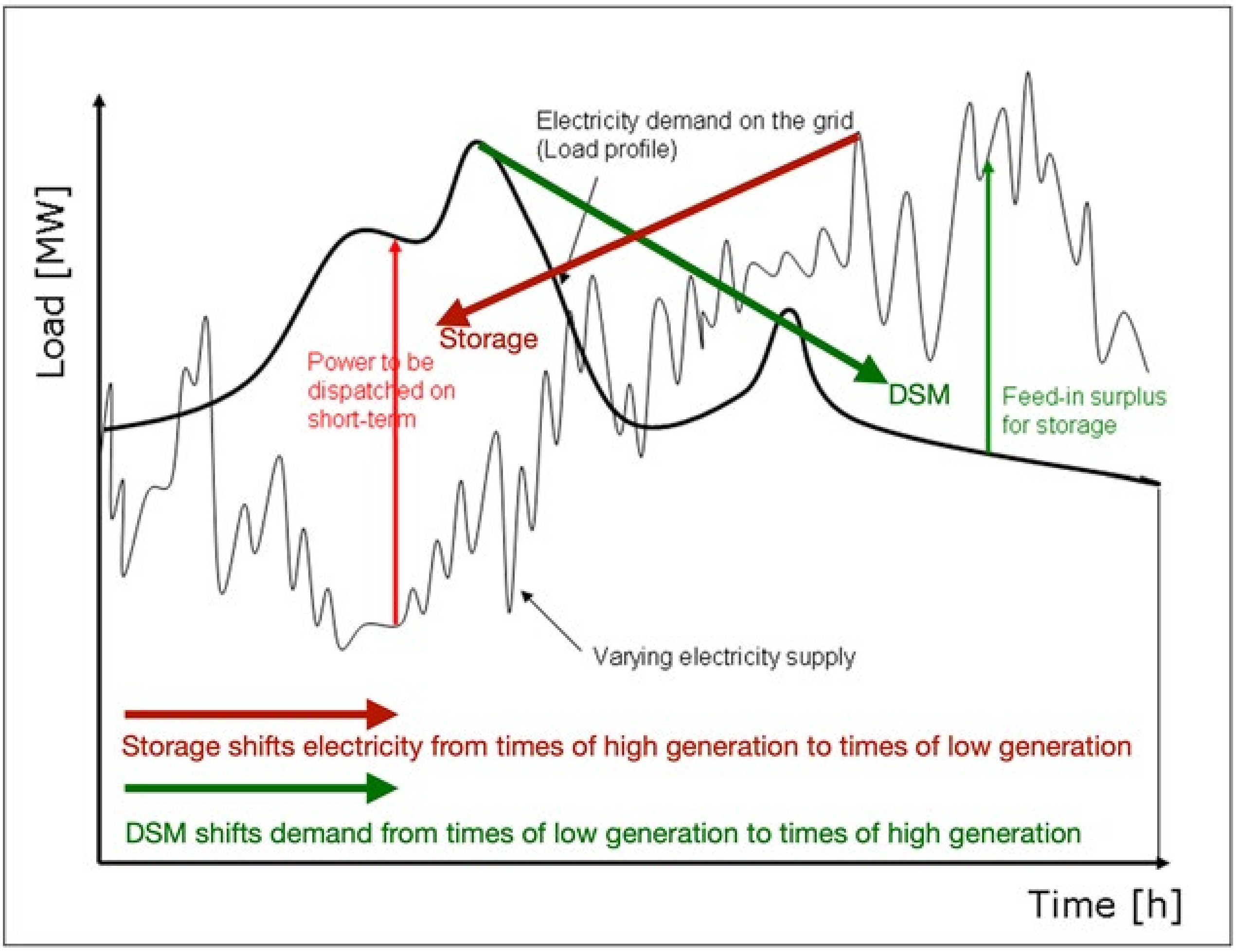



*Figure 34 Balancing electricity supply from variable renewable energy sources and electricity demand with the help of storage and Demand Side Management (DSM) (SRU, 2011)*

## Bottlenecks and Downregulation

Due to limitations in the electricity grid, the high potential production of wind energy cannot always be fully consumed. Usually, the excess power is sold and transported to neighboring areas. When the capacity of the grid cannot transport the required amount of electricity, a bottleneck-problem occurs. This is problematic, as it can cause blackouts if not handled properly. Up- and downregulation (i.e. turning production or consumption up or down) due to bottleneck problems locally or in neighboring price areas is referred to as special regulation.

As the electricity production is increasingly dominated by fluctuating energy sources, wind and solar power, the potential for bottleneck problems increases as well, demanding more downregulation. With the targets and plans in both Denmark and Germany to expand renewables, there will be a large increase in this fluctuating electricity production in the future. However, the areas of high consumption do not match the areas with good wind resources and space for large wind or solar power plants, and the time of production does not always match the time of consumption.

Being able to push consumption to a time with high production or being able to save electricity for a time of low production, is one of the keys to solving this issue and avoid the substantial financial losses following.

The issue with downregulation is already substantial in both Southern Denmark and Schleswig-Holstein. This is elaborated in the following.

**Internal bottlenecks and downregulation in Germany**

Since 2016, the downregulation has corresponded to 0.7-1 % of the gross electricity consumption in Germany, as the grid expansion and reinforcement has longer lead times than the construction of new renewable power generation capacities (Agentur für Erneuerbare Energien, 2020).

The bulk of downregulation has happened in Schleswig-Holstein and Niedersachsen as Figure 35 shows. These are the two federal states with the largest wind energy potential in and with low electricity demand. The estimated financial losses due to down regulation in 2018 were 653.4 mio. Euros in all of Germany and 294.4 mio. Euros in Schleswig-Holstein (Agentur für Erneuerbare Energien, 2020).

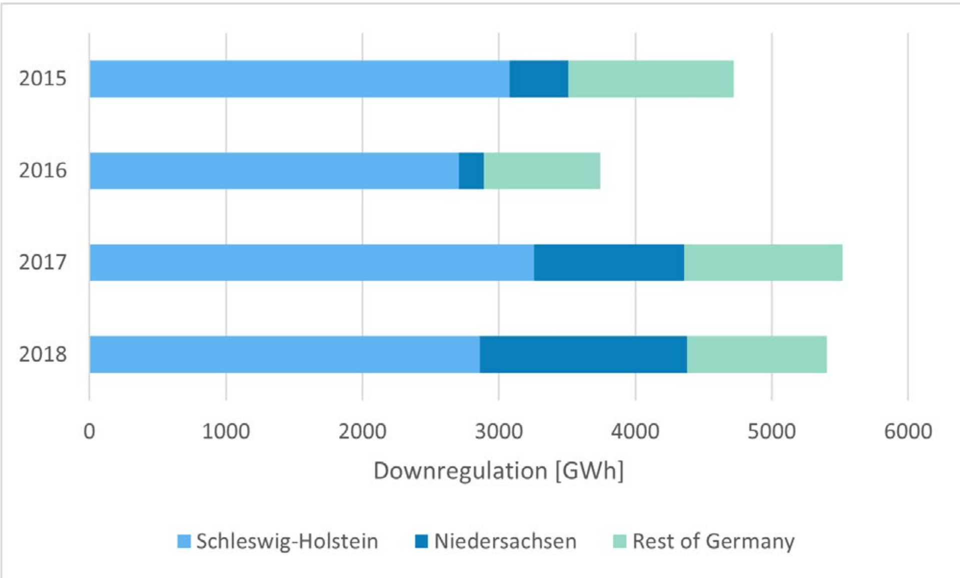



*Figure 35 Downregulated electricity production in all Schleswig-Holsten, Niedersachsen and the rest of Germany, 2015-2018. Data from Agentur für Erneuerbare Energien 2020*

**Internal bottlenecks downregulation in Denmark**

Already today, the Danish TSO Energinet requests downregulation from wind power producers to avoid these bottleneck-problems as is seen in Figure 36. The volumes have been increasing rapidly in recent years, and this development is expected to continue.

Energinet predicts that the electricity grid in Lolland and Falster will have a high risk of overload in 2025 – possibly the highest of any area in Denmark – as shown in Figure 27 and Figure 28. This is in part due to the increase in production capacity (see Figure 26). The predicted local downregulation needed to prevent this overload is up to 360 GWh in 2025 (Energinet, 2019a). This equals the yearly energy consumption of approx. 100,000 households and amounts to more than 50 times the internal downregulation in all of Denmark in 2019.

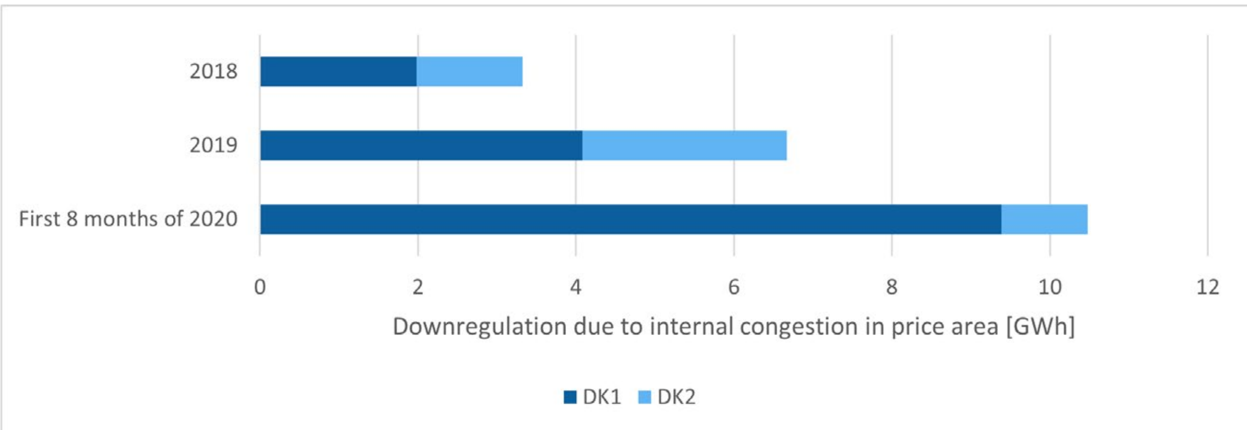



*Figure 36 Special downregulation due to internal congestion in either DK1 or DK2. Data from Reason codes for special regulation (Nord Pool, 2020a)*

**Supporting the German Grid**

Danish electricity producers are also part of solving the before mentioned bottleneck issues in Northern Germany. This is by far the largest reason for downregulation of Danish electricity producers: 89 % of all downregulation in Denmark in 2019 happened on request from TenneT, the TSO in the area including Schleswig-Holstein (Nord Pool, 2020b) (Energinet, 2019b).

TenneT might request downregulation of Danish electricity production in order to export their excess electricity across the border, which is often cheaper than internal regulation of the German grid.

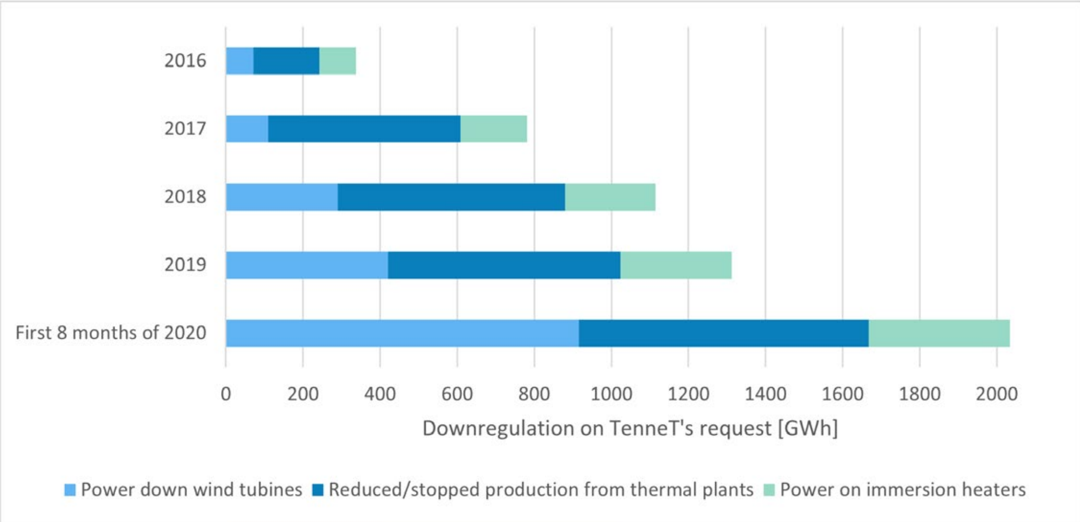



*Figure 37 Special regulation by Danish actors 2016-2019 on TenneT's request. Data from Statistik over Specialregulering (Energinet, 2019b) (Bernth, 2020)*

Details on special regulation provided by Danish actors are shown in Figure 37. The downregulation provided by wind turbines in 2019 of 420 GWh corresponds to 2-3 % of the total Danish wind production of 16 TWh that same year (Energistyrelsen, 2020e). This number has increased radically in 2020, in part due to high wind levels and the increased guaranteed minimum transmission capacity provided by Tennet (Energinet, 2020f). 8 % of the potential Danish production of wind has been stopped in the first 8 months of 2020 (Bernth, 2020).

Both Denmark and Germany are increasing the production of wind power, but the power grids do not yet support transportation of excess power. This shows a temporary need for storage and flexible consumption in the areas of high production to avoid bottleneck-problems and the following need for downregulation.

# WHY DG STORE?

## Future perspectives

Denmark and Germany are increasing production of renewable energy, such as wind, solar PV and biomass for electricity production. This is an important part of a transition towards a climate neutral society.

An increasing amount of wind and solar power creates two problems:

Firstly, electricity is no longer produced where it is consumed, and must be transported through the electricity grid. Currently, the capacity of the electricity grid does not match the need for transportation, which means that local overproduction can create bottlenecks in the electricity grid, as seen in both Denmark and Northern Germany. Expansions and extension of this grid has long lead times. Until the grid capacity is sufficient, a temporary need for local storage of energy arises to avoid downregulating production capacities.

Secondly, on the long term, both Denmark and Germany will have a 100 % renewable electricity production, based on high volumes of wind and solar power. When most of the electricity generation is fluctuating, consumption must be shifted in time to match the generation. Storage and demand side management are keys to creating this time-shift.

In Germany, the space-discrepancies will most likely be eliminated by expanding the electricity grid before the volumes of renewable energy in the electricity sector are large enough to create a demand for time-shifting. This means that the current demand for storage is temporary but will appear again once Germany approaches 100 % renewable electricity. Denmark will reach 100 % renewable electricity generation before 2030. The pace of the transition creates an overlap between the short and long term needs for storage, and thereby a continuous demand for these technologies.

The DG STORE project looks at local possibilities of storage on Lolland (DK) and in the Flensburg area (DE), which are both areas with an overproduction of electricity from renewable sources experiencing problems with bottlenecks and downregulation. By combining a local perspective on feasible solutions on the ground with a systems perspective, modelling the impact of local solutions for flexibility, the project will help show the potential of storage technologies in a climate-neutral energy system.

To read more about DG STORE, please visit the project website: [www.dg-store.eu](http://www.dg-store.eu).

## OTHER PROJECTS

DG STORE gets inspiration and knowledge from other projects on storage and flexibility in the electricity grid. Some of these are presented here.

**EcoGrid**

An award-winning, Bornholm-based project showing great potential of demand side management of electric heating devices provided by consumers. Not only is demand side management possible with existing technologies and markets, it also can be done without compromising on consumer comfort.

Read more at: https://beof.dk/om-os/udviklingsprojekter/ecogrid-20/

**Trade with Local Flexibility on Lolland**

The Danish TSO, Energinet, has done a pilot project on Lolland, investigating the use of local regulation of production and consumption to mitigate bottleneck problems in the area. By geo-tagging participating units, flexibility can be requested from units in the specific area of a predicted bottleneck.

Read more at: https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Pilotprojekt---Handel-med-lokal-fleksibilitet/

**FUTURE**

Danish and Swedish regions in Greater Copenhagen are working to integrate and store renewable energy in buildings, as well as increase the resource efficiency of materials.

Read more at: https://www.gate21.dk/future/

**GOFLEX**

GOFLEX innovates, integrates and demonstrates existing smart-grid technologies enabling the cost-effective use of energy flexibility in distribution grids for regional energy market actors. The GOFLEX platform will provide features to manage and trade flexibility with consumers, generators and prosumers.

Read more at: https://www.goflex-project.eu/

**PEKIVE**

PEKIVE investigates the use of AI and machine learning to reduce the energy consumption of buildings and have already shown a 30 % saving in one of their cases. The AI uses information about the thermal profile of the building, local weather reports and energy prices, always with a healthy indoor climate as a priority.

Read more at: https://elforsk.dk/projektdatabase/pekive-prognosestyret-elopvarmning-baseret-pa-kunstig-intelligens-variable-elpriser and https://elforsk.dk/nyheder/projektresultat/kunstig-intelligens-overrasker-positivt-drift-bygninger

**FED**

Flexible Energy Denmark (FED) aims to make the Danish electricity consumption flexible in order to use excess power production from wind and solar plants.

Read more at: https://www.flexibleenergydenmark.dk/

**Carpe Diem**

Carpe Diem has worked on the development of an intelligent energy management system of micro grids, like villages with a high share of renewable energy production, and integration of storage.

Read more at: https://www.interreg5a.eu/wp-content/uploads/2020/04/Abschlussbericht.pdf

**New 4.0**

The project tried to develop different technologies for the future of energy transition in Northern Germany. Among the twelve different project targets NEW 4.0 are targets aimed at the development of 'Innovative system management', 'Storage technologies', 'Sector coupling', 'Grid reinforcement' and 'Demand side management'.

Read more at: https://www.new4-0.de/energiewende/

Read more at: https://www.new4-0.de/energiewende/#projektziele

# REFERENCES

50Hertz Transmission GmbH et al. (2020) Szenariorahmen zum Netzentwicklungsplan Strom 2035, Version 2021-Entwurf der Übertragungsnetzbetreiber. Available at: https://www.netzentwicklungsplan.de/sites/default/files/paragraphs-files/Szenariorahmenentwurf_NEP2035_2021.pdf.

Agentur für Erneuerbare Energien (2020) Bundesländer-Übersicht zu Erneuerbaren Energien. Strom. Einspeisemanagement/Ausfallarbeit. Available at: https://www.foederal-erneuerbar.de/uebersicht/bundeslaender/W%7CBY%7CB%7CBB%7CHB%7CHH%7CHE%7CMV%7CNI%7CNRW%7CRLP%7CSL%7CSN%7CST%7CSH%7CTH%7CD/kategorie/strom/auswahl/880-einspeisemanagementa/sicht/diagramm/#goto_880 (Accessed: 25 November 2020).

Alexrk2 (2013) 'Planned high-voltage grid expansion in Germany according to the Federal Requirements Plan'. Available at: https://commons.wikimedia.org/wiki/File:Karte_BBPlG-Vorhaben.png.

Bernth, M. (2020) 'Paradokset vokser: 2020 bliver rekordår for standsede vindmøller i Danmark', Ingeniøren. Available at: https://ing.dk/artikel/paradokset-vokser-2020-bliver-rekordaar-standsede-vindmoeller-danmark-239892 (Accessed: 28 October 2020).

Bundesregierung (2020) Ausstieg aus der Kernkraft. Available at: https://www.bundesregierung.de/breg-de/themen/energiewende/energie-erzeugen/ausstieg-aus-der-kernkraft-394280 (Accessed: 24 October 2020).

Christiansen, H. and Baescu, O. (2020) TU årsrapport for Danmark 2019.

Clean Energy Wire (2020) Germany's energy consumption and power mix in charts. Available at: https://www.cleanenergywire.org/factsheets/germanys-energy-consumption-and-power-mix-charts (Accessed: 24 October 2020).

Danmarks Naturfredningsforening (2018) 'Myte: Elbiler kan ikke køre langt nok'. Available at: https://www.dn.dk/nyheder/myte-elbiler-kan-ikke-kore-langt-nok/ (Accessed: 1 December 2020).

Danmarks Statistik (2020) 'Vigende udvikling i bilsalget'. Available at: https://www.dst.dk/da/Statistik/nyt/NytHtml?cid=29924.

Dansk Fjernvarme (2020) Fakta om fjernvarme. Available at: https://www.danskfjernvarme.dk/presse/fakta-om-fjernvarme (Accessed: 30 November 2020).

Ea Energianalyse (2020) Roadmap for elektrificering i Danmark.

Energinet (2019a) 'Behovsvurdering for systemydelser 2020'. Available at: Dok. 17/05627-233.

Energinet (2019b) 'Statistik over specialregulering 2016-2019'. Available at: https://energinet.dk/El/Systemydelser/Nyheder-om-systemydelser/Specialregulering.

Energinet (2020a) 'Behovsanalyse for eltransmissionsnettet 2020'.

Energinet (2020b) Energi Data Service: Production per Municipality - Dataset. Available at: https://www.energidataservice.dk/tso-electricity/communityproduction (Accessed: 28 September 2020).

Energinet (2020c) Kabel til Storbritannien. Available at: https://energinet.dk/Anlaeg-og-projekter/Projektliste/Viking-Link (Accessed: 1 December 2020).

Energinet (2020d) Kapacitetskort 2020. Available at: https://energinet.dk/Om-publikationer/Publikationer/Kapacitetskort-2020.

Energinet (2020e) Miljødeklarationer: Historiske data samt beregner. Available at: https://energinet.dk/El/Gron-el/Miljoedeklarationer (Accessed: 25 September 2020).

Energinet (2020f) Minimumskapacitet på DK1-DE/LU, jf. Joint Declaration og Tennet Commitment. Available at: https://energinet.dk/El/Nyheder-om-elsektorens-rammer-og-regler/2020/02/27/Minimumskapacitet-paa-DK1-DE-LU (Accessed: 22 December 2020).

Energinet (2020g) Redegørelse for elforsyningssikkerhed 2020.

Energistyrelsen (2019) Energistatistik 2018. Available at: https://ens.dk/service/statistik-data-noegletal-og-kort/maanedlig-og-aarlig-energistatistik.

Energistyrelsen (2020a) 'Analyseforudsætninger 2020 (af20) datasæt', Updated 23. Available at: https://ens.dk/service/fremskrivninger-analyser-modeller/analyseforudsaetninger-til-energinet.

Energistyrelsen (2020b) Basisfremskrivning 2020 -Danmarks Klima-og Energifremskrivning. Available at: http://www.ens.dk/basisfremskrivning.

Energistyrelsen (2020c) Dansk klimapolitik. Available at: https://ens.dk/ansvarsomraader/energi-klimapolitik/fakta-om-dansk-energi-klimapolitik/dansk-klimapolitik (Accessed: 30 November 2020).

Energistyrelsen (2020d) Download færdige kort. Available at: https://ens.dk/service/statistik-data-noegletal-og-kort/download-faerdige-kort (Accessed: 30 November 2020).

Energistyrelsen (2020e) Energistatistik 2019. Available at: https://ens.dk/sites/ens.dk/files/Statistik/energistatistik2019_dk.pdf.

Energistyrelsen (2020f) Teknologikatalog for produktion af el og fjernvarme. Available at: https://ens.dk/service/fremskrivninger-analyser-modeller/teknologikataloger/teknologikatalog-produktion-af-el-og (Accessed: 24 September 2020).

European Commission (2018) Study on the quality of electricity market data of transmission system operators, electricity supply disruptions, and their impact on the European electricity markets. Final report. Brussels. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/dg_ener_electricity_market_data_-_final_report_-_22032018.pdf.

Eurostat (2020) Data Browser Beta, Final energy consumption by product. Available at: https://ec.europa.eu/eurostat/databrowser/view/ten00123/default/table?lang=en (Accessed: 24 October 2020).

Gaarsmand, R. and Kjær, T. (2018) 'Varmedata Lolland Kommune'.

IEA (2019) Denmark - Data browser - Electricity generation by source. Available at: https://www.iea.org/countries/denmark (Accessed: 1 December 2020).

Klima- Energi- og Forsyningsministeriet (2018) Energiaftalen 2018. Available at: https://kefm.dk/aftaler-og-politiske-udspil/energiaftalen (Accessed: 30 November 2020).

Klima- Energi- og Forsyningsministeriet (2020) Klimaaftale for energi og industri mv. 2020. Available at: https://fm.dk/media/18085/klimaaftale-for-energi-og-industri-mv-2020.pdf.

Kollektiv Trafik Forum (2020) Movia sender 47 nye elbusser i drift næste år. Available at: https://www.kollektivtrafik.dk/movia-sender-47-nye-elbusser-i-drift-naeste-aar/1502 (Accessed: 1 December 2020).

Landesregierung Schleswig-Holstein (2018) Bericht der Landesregierung: Energiewende- und Klimaschutzgesetz Schleswig-Holstein. Ziele, Maßnahmen und Monitoring 2018. Energiewende- und Klimaschutzgesetz Schleswig-Holstein. Available at: http://www.landtag.ltsh.de/infothek/wahl19/drucks/00800/drucksache-19-00818.pdf.

Nord Pool (2020a) Reason codes for special regulation - Market data. Available at: https://www.nordpoolgroup.com/Market-data1/Regulating-Power1/Special-Regulation1/Reason-codes/NO1/NO1/?view=table (Accessed: 28 October 2020).

Nord Pool (2020b) Regulating power per area - Market data. Available at: https://www.nordpoolgroup.com/Market-data1/Regulating-Power1/ (Accessed: 28 October 2020).

SRU (2011) Pathways towards a 100 % renewable electricity system. Special Report. Berlin. Available at: http://www.umweltrat.de/SharedDocs/Downloads/

EN/02_Special_Reports/2011_10_Special_Report_Pathways_renewables.pdf?__blob=publicationFile.

Stadtwerke Flensburg (2019) Änderungsgenehmigungsantrag Neubau Kessel 13. Flensburg. Available at: https://www.uvp-verbund.de/documents/ingrid-group_ige-iplug-sh/60FBCCF1-C2A9-48F5-B062-4283A71A8F99/01_Antrag.pdf.

Stadtwerke Flensburg (2020a) Unsere Leitungsnetze aus technischer Sicht. Available at: https://blog.stadtwerke-flensburg.de/artikel/unsere-leitungsnetze-aus-technischer-sicht (Accessed: 25 November 2020).

Stadtwerke Flensburg (2020b) Zahlen, Daten, Fakten. Available at: https://stadtwerk-mit-zukunft.de/stadtwerke-flensburg/zahlen-daten-fakten/ (Accessed: 25 November 2020).

Stokkemarke Lokalblad (2019) Ny fjernvarmeleverandør i Stokkemarke. Available at: https://lollandforsyning.dk/wp-content/uploads/2019/03/Artikel-i-Stokkemarke-lokalblad.pdf.

Umweltbundesamt (2020) Erneubare Energien in Deutschland. Daten zur Entwicklung im Jahr 2019. Berlin. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2020-04-03_hgp-ee-in-zahlen_bf.pdf.

Wikipedia (2020) Bundesbedarfsplangesetz. Available at: https://de.wikipedia.org/wiki/Bundesbedarfsplangesetz (Accessed: 25 November 2020).