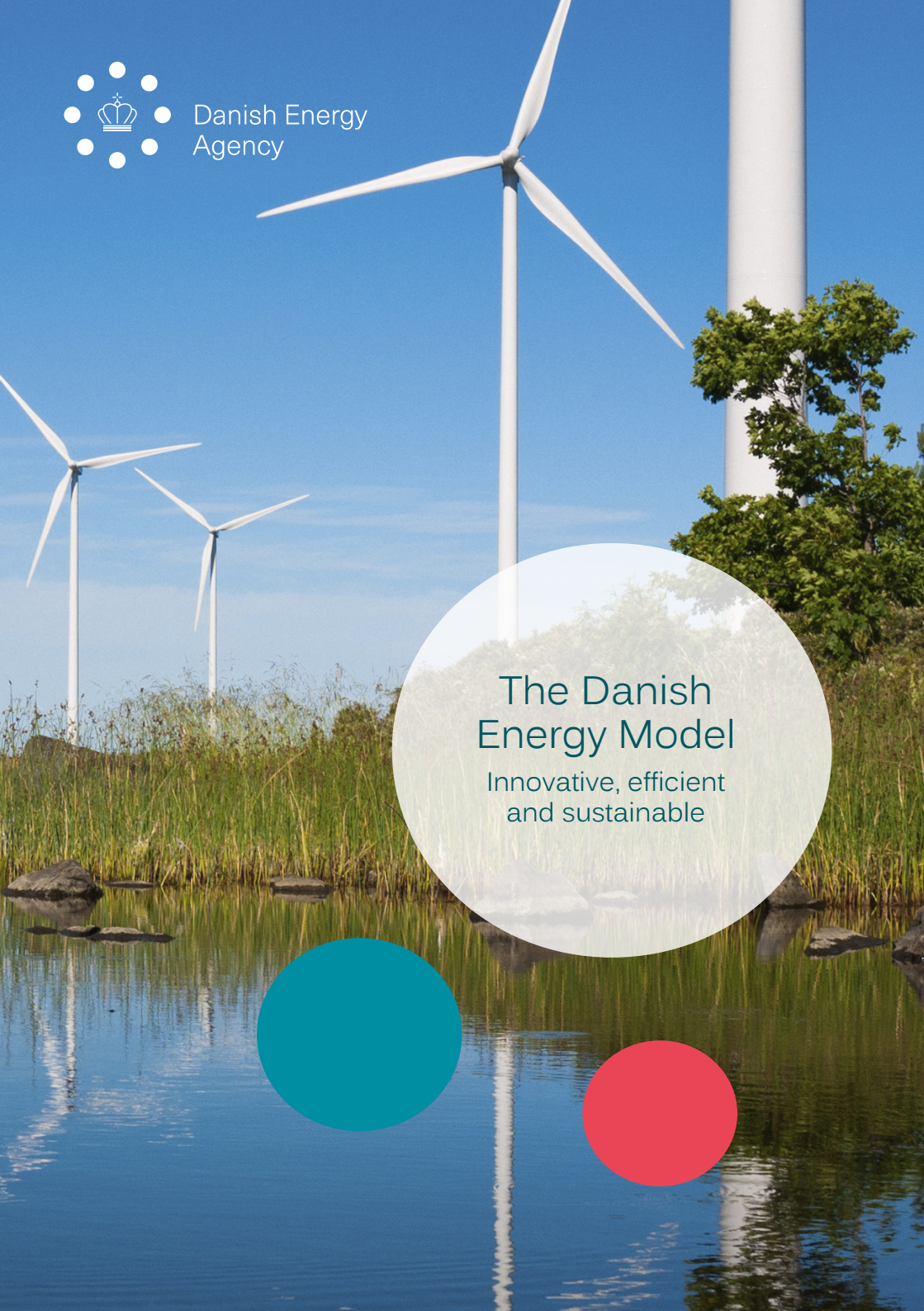
Danish Energy
Agency
The Danish
Energy Model
Innovative, efficient
and sustainable

The Danish Energy Agency

Preface

The Danish Energy Model has shown that through persistent, active and cost effective energy policy with ambitious renewable energy goals, enhanced energy efficiency and support for technical innovation and industrial development, it is possible to sustain significant economic growth, a high standard of living and a high level of security of energy supply, while reducing fossil fuel dependency and mitigating climate change.

In a nutshell: energy savings, optimized manufacturing and investments in green energy technology are good value for money.

Denmark has reduced the adjusted greenhouse gas emissions by more than 30% since 1990. With current measures in place, the Danish Energy Agency estimates that emissions will be approximately 40% lower by 2020 – surpassing Denmark's legally binding EU commitment of 34%. Denmark has the highest contribution of non-hydro renewables in any electricity system worldwide: 66% in 2015. In 2015, more than 40% of the Danish electricity consumption was based on wind power; by 2020 this figure will likely be more than 50%.

The Danish government has set a number of targets for the further development of the energy sector:

Continuing low-carbon energy sector transition in a cost effective manner

Maintaining Denmark's leading position in a number of low-carbon technologies and systems

And ultimately, making Denmark self-reliance on renewable energy in 2050

The Danish Energy Model documents that the transition to 21st century energy is doable – and affordable.

Morten Bæk
Director General
Danish Energy Agency

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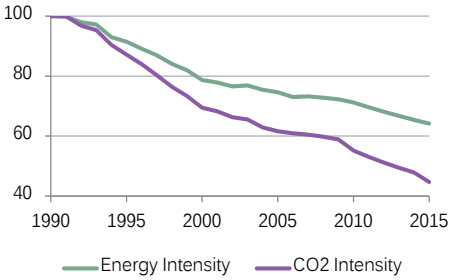
Low-carbon economic growth and job creation

The results of clear political direction have been significant and convincing: the Danish experience shows that through persistent and active energy policy focused on enhanced energy efficiency and ambitious use of renewables in a cost efficient manner, it is possible to sustain significant economic growth and simultaneously reduce fossil-fuel dependency while protecting the climate and environment.

The Danish economy's energy consumption is among the lowest in the world relative to gross output. Denmark has become one of the world's most energy efficient economies. Since 1990, Danish GDP has increased by 44%. During this period, the domestic energy consumption has declined by 8% and the adjusted carbon emissions by 36%. This development has not only benefitted the competitiveness of Danish enterprises through lower energy costs and less exposure to highly volatile fossil fuel prices, but also fostered new products and industries. Green products and services are defined as products which reduce pressure on the environment, for example energy saving products and the service of installing renewable energy systems. In 2015 Denmark produced green products and services for EUR 25.8 billion, half of which is related to renewable energy and one seventh to energy efficiency. The green sector employs almost 67,000 people in Denmark. As an example, the Danish wind energy sector currently employs more than 31,000 workers[1] and the Danish export of wind energy technology in 2015 accounted for EUR 6.5 billion[1]. The total export of energy technology accounted for more than 10% of Denmark's total exports of goods in 2015. Green energy technology accounted for almost 60% of that number.

[1]The Danish Wind Industry Association (DWIA)

Danish trends - Energy and CO2 intensity (1990=100)

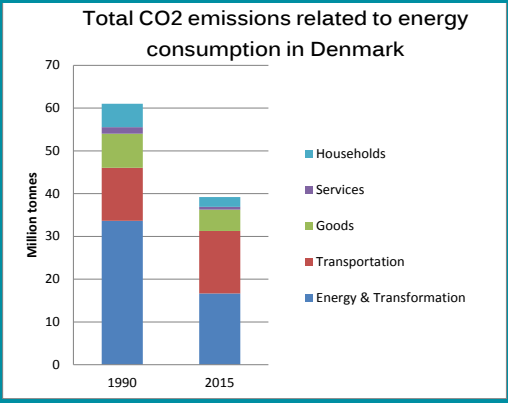


Source: Danish Energy Agency

Declining energy consumption and carbon emissions

Most of the 8% decline in the **gross energy consumption** in Denmark between 1990 and 2015 is due to a 28% drop in fossil fuel consumption relative to the gross energy consumption partly substituted by a 6% increase in contribution from wind energy and a 14% from bio fuels and other renewable energy sources. In 2015 renewable energy sources accounted for 28% of the gross energy consumption of Denmark. In the same period, energy conversion efficiency has been boosted significantly, reducing conversion losses by 34% or 9% relative to gross energy consumption. The main reason for this improvement has been a massive increase in district heating and wind energy capacity. These two energy sources have increased their overall contribution by 9% compared to the gross energy consumption in the period. With a 44% increase in real GDP from 1990 to 2015 combined with almost flat net energy consumption, the end-user energy efficiency has also been improved significantly. As an example, the manufacturing sector has boosted the gross value added by almost 30% but reduced final energy consumption by more than 20% in the period. Danish households have increased real consumer spending by more than 40% in the period but only increased net energy consumption by almost 10%.

As for **CO_2 emissions** related to energy, the main contributors to the 36% drop in Danish emissions since 1990 is energy conversion (electricity and heat generation) by 56% mainly due to an almost tripling of energy generated from renewable energy sources, plant efficiency and CHP plants. Goods manufacturing and household consumption contributed with 38% and 58% emission reductions, respectively. As for power generation, reduction in fossil fuel based sources and power plant optimization has reduced this sector emissions by 60% compared to 1990 emissions.



Source: Danish Energy Agency

Setting the course

Denmark has a long tradition of active energy policy, initiated as a reaction to the first oil crisis in 1973. Over the years, a broad consensus in the Danish Parliament has been utilized to transition Denmark's energy system towards reduced energy consumption, increased decentralized energy production and increased utilization of renewable energy sources. Consistent, determined and long-term political objectives have formed the foundation of the low-carbon transition of the Danish energy sector.

Scenarios

In 2007, the Danish Commission on Climate Change Policy was formed to ensure a cost efficient transition of a low carbon energy future for Denmark. The Danish Energy Agency supported the Commission's work through detailed scenario analyses, to investigate both technical possibilities and related costs for Danish society in reaching the goal of a low carbon energy system by 2050. This analysis shows that it is possible to cost-efficiently design different energy systems which all meet the target of a low carbon energy system by 2050. All scenarios assume vast energy savings as part of the strategy to reach a low carbon energy system. A business as usual based scenario was used as a reference, and the analysis shows that both the wind and biomass scenarios are within 10% of additional costs compared to the fossil fuel based scenario. A low carbon transition of the Danish energy system not only requires further improvement of energy efficiency and new low carbon energy sources, but also further energy cooperation with Denmark's neighboring countries to reduce costs and secure stability and security of energy supply. Denmark fully supports the creation of the EU Energy Union as a way to improve energy security and reduce green transition costs.

To further secure a cost efficient low carbon energy transition, the Danish government has formed a new Energy Commission to analyze the next step after reaching the 2020 target for energy efficiency, renewable energy supply and greenhouse gas (GHG) reduction.

Innovation and system development

Research, development and demonstration of new technologies and systems have been critical elements in establishing a Danish stronghold in the energy sector. Public-private sector cooperation, coupled with stable political and regulatory frameworks, has fostered important innovation and breakthroughs in energy concepts and -systems. The foundation of the low-carbon transition has been threefold: energy efficiency, renewable energy and system integration including electrification.

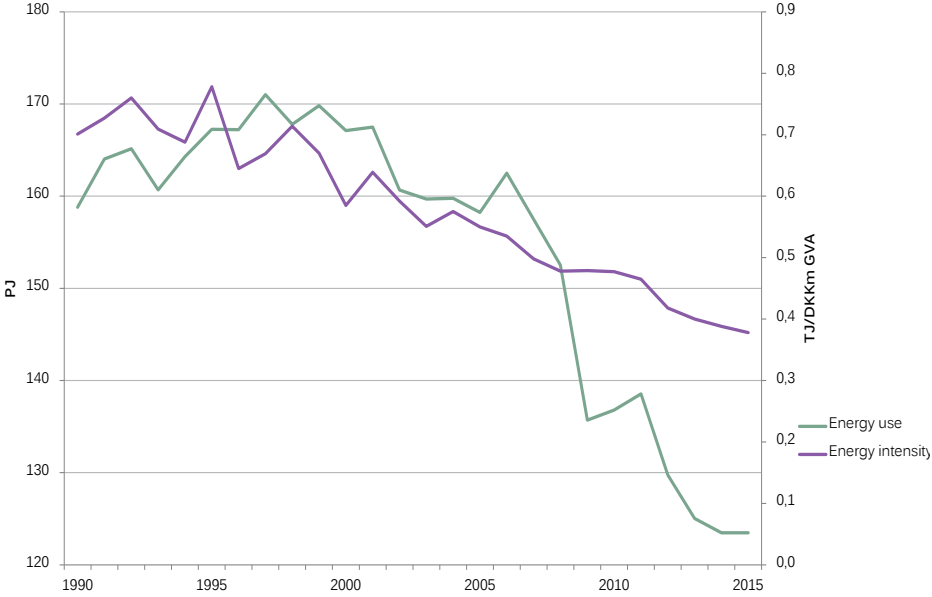
Energy efficiency

Energy efficiency is a vital element in the green transition of the energy sector. Without extensive energy efficiency improvements, it would have been disproportionally expensive to meet energy demands with new and initially more expensive energy sources like renewable energy. Successful energy efficiency deployment enables meeting society's demand for various energy services more efficiently and effectively, so that energy consumption is reduced. Results are achieved in part by transitioning to more energy efficient technologies and solutions, but also highly dependent on increasing energy consciousness and altering consumer behavior.

Denmark has achieved remarkable results in energy efficiency performance for households, manufacturing and energy production. For instance, energy consumption in buildings has been reduced by 45% per square meter since 1975. For the manufacturing sector, the energy intensity has been reduced by more than 2% per annum the last ten years. According to a study[2] the gains in energy efficiency has improved cost competitiveness in the Danish manufacturing sector by 9%, due to oil price increases over the last decade.

[2] Danmarks Nationalbank Monetary Review, 2nd Quarter, 2014, Energy efficiency and competitiveness

Energy use and intensity in the Danish manufacturing sector



Note: Energy (E) use in PJ and E intensity in TJ / mio EUR gross value added (2010-prices) from 1990 to 2013

Support for energy efficiency measures

Potential remains for cost effective energy efficiency improvements. These exist in all sectors and areas of use. Significant improvements on national energy efficiency performance can be achieved with products and technologies that are already developed and available as consumer solutions. Often, it will be cost effective for consumers to use existing solutions; however, energy efficiency improvements do not come about automatically. Active efforts are needed to promote additional efficiency improvements and savings. Danish energy policy therefore contains a number of initiatives to increase energy efficiency improvements in order to minimize energy use and energy waste in all sectors.

In addition to more efficient energy production, a number of initiatives have been carried out to increase the efficiency of end-user consumption, that is, consumption by consumers and enterprises. Danish environmental- and energy taxes contribute to a better reflection of the environmental costs of production, use and disposal in consumer prices on energy.

By formulating schemes in close dialogue with industry, knowledge about challenges and possibilities are integrated in the measures.

Initiatives include:

- Energy labelling of buildings
- Building codes focusing on energy consumption
- Electricity saving trusts
- Energy labelling of appliances
- Energy savings in the public sector
- Energy efficiency obligation schemes

Renewable Energy

Despite almost no hydropower resources, Denmark has managed to become a global leader in renewable energy generation. Renewable energy's share of final energy consumption in Denmark has been steadily increasing since 1980. Today, almost 30% of Denmark's final energy consumption is covered by renewable energy.

Measuring electricity supply alone, renewable energy today accounts for well above 50% of domestic generation, which is mainly due to the incorporation of wind energy in electricity production. Denmark today has more than 5 GW of installed wind energy capacity, of which almost 1.3 GW are offshore wind turbines. On windy days, wind turbines in Denmark produce more than the domestic demand.

Changes in the Danish overall energy mix have resulted in a substantial reduction

of emissions from energy production. CO_2 emissions from electricity production have decreased by 60% in the period 1990 to 2015. Less than half the amount of CO_2 is emitted when producing one unit of GDP in 2015 compared to 1990 and per capita emission has been reduced by more than 40%.

Reaping the full benefits of new renewable energy technologies has caused radical changes to the Danish energy system and networks. Danish experience shows that flexibility in conventional production in combination with strong transmission and distribution networks, and larger exchange of power with neighboring countries in order to increase balancing areas, are important components in overcoming challenges.

Renewable energy has contributed to a

Efficient and effective support for renewable energy

Promoting renewable energy requires a favorable investment climate, a developed power grid and long-term planning.

High initial investment cost and lack of fuel costs are the main differences between wind or solar energy and most conventional power sources. Stimulating demand through financial and market support has been a central element in promoting the expansion of renewable energy in Denmark. A positive investment climate has been created with priority grid access and resource based feed-in tariffs. Feed-in tariffs for offshore wind are settled by tender and feed-in premiums with a cap regulate the support for onshore wind power.

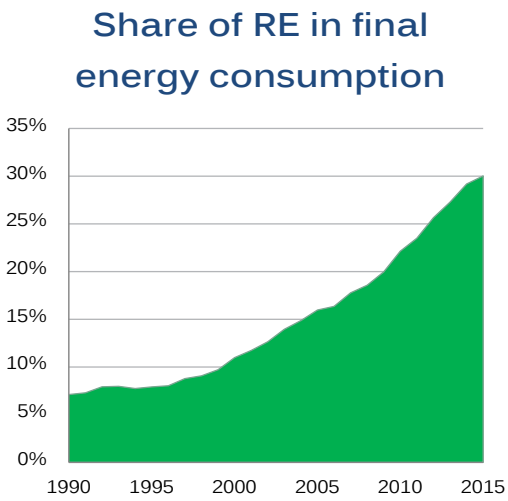
Central and long-term planning has ensured timely and relevant investments in the power grid and system. Thus the grid and system have been developed incrementally in order to handle the steady increase in fluctuating renewable energy production. Strategic planning of future grid investments follows the current political energy agreement with adopted measures and policies toward the Danish government's long-term goal of fself-reliance on renewable energy.

Mapping available resources are fundamental in physical planning to estimate production of potential sites. Ambitious targets, long-term planning and strong and stable political framework conditions have paved the way for significant private investments by creating a positive and secure long-term investment climate. The Danish Energy Agency functions as a "one stop shop" for permits, where all relevant information is gathered. This makes necessary processes more streamlined and effective.

sharp decline in carbon emissions, but also enhanced the security of energy supply by utilizing domestic energy resources like wind, solar and biomass. Going forward, further expansion of renewable energy capacity and sources is an important element in meeting the government's long-term vision to make Denmark able to cover its energy demand by renewable energy generation and sources.

Analyses show that the costs of introducing renewable energy in Denmark have been relatively high initially. However, gradually declining renewable energy costs and gradually increasing prices for fossil fuels have made renewable energy sources increasingly competitive compared with traditional energy sources. Today, onshore wind is the cheapest power generation technology when adding new capacity in Denmark even excluding indirect costs for conventional fossil fuel based generation options. These costs are mainly related to cost for negative effects of emissions such as CO_2, SO_x and NO_x. These emissions are adding negative health, environment and climate effects and consequently costs for individual citizens and society as a whole.

It is worth mentioning that Danish energy taxation and participation in the European Emission Trading System (ETS) is meant to correct some of these market imperfections making energy market participants and investors aware of indirect generation costs. Also it should be noted that emissions levels per produced MWh is very low in Denmark due to strict emissions and efficiency standards (CO_2 per produced MWh). The calculations also includes balancing cost for fluctuating renewable energy sources like wind and solar, which is on a level of EUR 1-2 per MWh for the Danish power system.



Source: Danish Energy Agency

How is Denmark integrating renewable energy today and in the future?

Some days the power production from wind turbines in Denmark exceeds the domestic demand for electricity, and on average the fluctuating wind energy supplied 42% of electricity consumption in 2015. How is Denmark managing to integrate very large shares of fluctuating wind energy nearly without wind power curtailment, as we often see in other countries?

Most would point to the resource endowment of the Nordic countries, i.e. the synergy between hydro-, wind- and thermal power in combination with a strong integration with neighboring grids of Europe, including the well-developed NordPool power exchange, as the primary factors. Denmark can freely buy and sell electricity to balance the fluctuating electricity production from wind. But reality is more complex, and includes a number of innovative features.

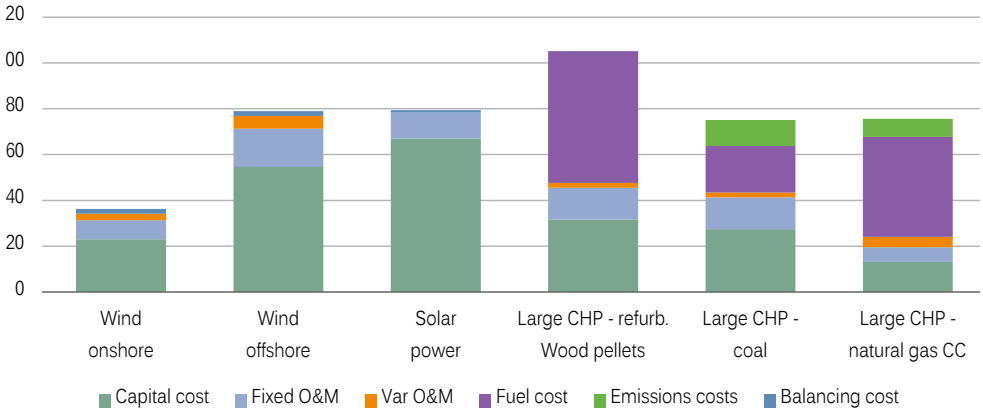
- Integrating heat supply with electricity balancing. Half of our electricity is produced by small combined heat- and power plants. This system has been designed with flexibility allowing for varying proportions of heat and electricity production, and also has built-in heating storage that allows for continuing the heat supply, while reducing the electricity production at the CHP plants when there is ample wind power available in the system.
- Innovation in thermal power plant flexibility, which can vary their daily output and quickly adapt to the fluctuating production from wind. In most parts of the world thermal power plants are designed to run constant outputs, and the owners will resist implementing increased flexibility in daily operations. The speed of power production regulation in Denmark is larger than in other countries, and the minimum level of output is unusually low in Danish power plants due to technical retrofits and adjustments.
- Innovation in the incorporation of advanced wind forecasting in the operations of power system control and dispatch. Such advanced forecasting, used by the Danish Transmission System Operator **Energinet.dk**, has increased the ability to integrate and balance high shares of renewables.
- Advanced functions of the electricity market allowing the CHP plants and the coal power plants to benefit not only from selling to

the wholesale market in which their share of trade is decreasing due to increased priority production from renewables. They can also profit from selling their services to the so called 'ancillary markets', which provides a number of services required for a well-functioning power system.

Further increasing the share of renewable energy will require more flexibility in the power system. Denmark is therefore strengthening international connections, and introducing technical measures that will allow for more flexibility and more rapid response in the demand for power. Furthermore, it is important to note that modern wind-turbines, due to technological improvements, today can provide part of the foundation to ensure power system stability, a role that previously was reserved for thermal power plants.

The combination of circumstances in Denmark might be unique, but our experience has attracted huge international attention and has been shared with important Chinese institutions in the ongoing cooperation between the Danish Ministry of Energy, Utilities and Climate and key Chinese authorities in the field of energy, like National Energy Administration (NEA), State Grid and others. The Chinese authorities are using Danish experiences to reduce curtailment of wind power, and working closely with Danish authorities to achieve a general transformation of the Chinese energy sector in a green and sustainable direction.

Levelized cost of energy -New power capacity in Denmark



Note: Coal based on supercritical plants. Source: Danish Energy Agency

Synergies - energy system integration and development

Focusing on broader interactions and systems, as opposed to individual components and concepts, is an important aspect of the Danish energy model. The Danish energy model is characterized by a holistic view of energy planning, with emphasis on integration of for instance heat and power production, and establishing synergies between taxation schemes and policy support frameworks for renewable energy.

Furthermore, prudent interaction within the power and heating sector, i.e. CHP production, use of heating storage in the district heating system and increased use of electricity for heating accompanied by increased deployment of heating pumps and electrical boilers, will further improve the efficiency in the energy sector and mitigate the challenges of integrating variable renewable energy sources in the power system.
An effective integration and support for renewable energy sources in Denmark combined with a well-functioning open power market in the region (NordPool) has ensured that Danish power prices are not significantly higher than other European countries, even including the cost of supporting generation and integration of large amounts of renewable energy.

Climate change – setting and achieving ambitious targets

The future foundation for Danish energy policy is based on broadly supported political agreements, with the
Energy Agreement of 2012 as the most important element for the further transition toward 2020.

The Danish Government has established the long-term goal of making Denmark self-reliance on renewable energy in 2050, meaning that the entire energy demand – electricity, heating, industry and transportation – is to be met by renewable energy generation by 2050. Already in 2030 the Danish government is aiming at that 50% of the Danish gross energy consumption is to be supplied by renewable energy generation.
The Energy Agreement is the roadmap for development of energy supply and demand for the period 2012–2020. This agreement contains a wide range of ambitious initiatives, bringing Denmark a good step closer to the target of a renewable energy supply that matches the energy demand. Through expanded offshore wind production and use of biomass, renewables are expected to cover more than 70% of Danish electricity production by 2020. The Energy Agreement and current results and projections shows that Denmark will more than fulfills its obligations toward the EU 2020 targets within energy efficiency, renewable energy and reduction of carbon emissions (20-20-20 targets).

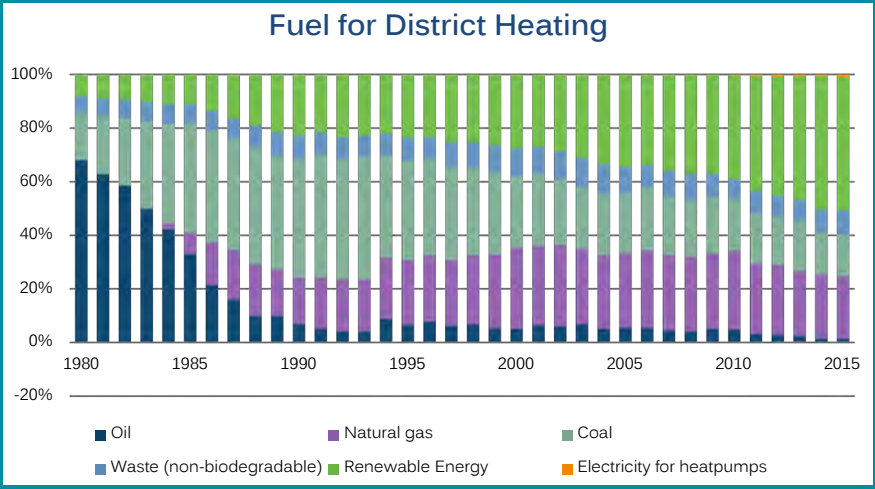
Combining heat and power production

Combining heat and power generation has been a key component in the development of the energy sector in Denmark creating a cost effective heat and power supply. The average cost of receiving heat and hot water from district heating only amounts to 3% of the average household income. The distribution of heat through district heating in Denmark has been one of the key drivers in reductions of gross energy consumption and CO_2 emissions from the energy sector. District heating supplies more than 60% of all households in Denmark with heat and hot water.

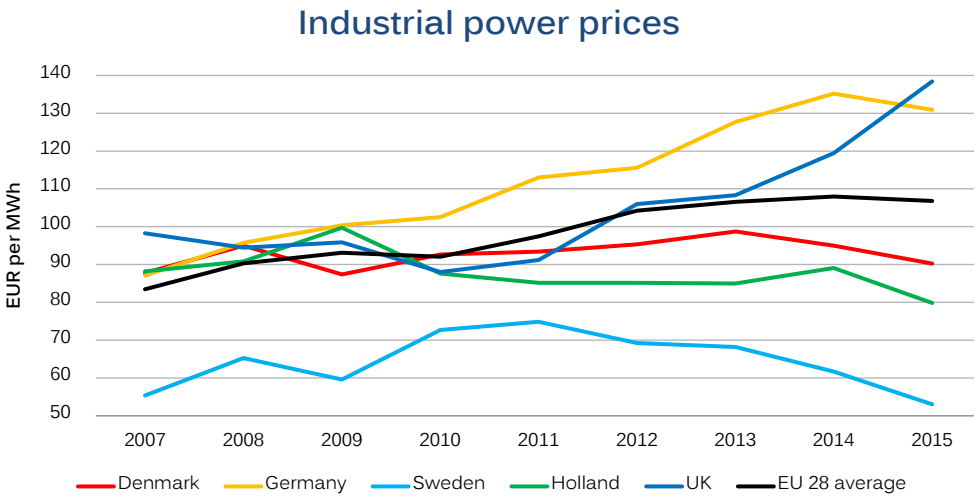
Almost 70% of the heat distributed through district heating in Denmark is generated in combined heat and power plants (CHP).

CHP's accounted for close to 80% of the thermal power generation in Denmark in 2015. A transformation of CHP from fossil fuel to biomass and new dedicated biomass CHP and heat capacity means that close to 50% of the district heating produced in 2015 was from renewable energy. For Danish society, the gross energy consumption has been reduced by more than 10% due to combined heat and power.

The implementation of district heating and combined heat and power has throughout the years, apart from the planning procedures, been supported by a variety of different support mechanisms. These vary from tax exemptions, feed-in tariffs to investment grants.



Source: Danish Energy Agency



Note: Electricity prices including tariffs for businesses using 2-20GWh annually. Source: Danish Energy Agency

Strong international ties and cooperation

A significant amount of Danish energy system innovation has been developed in close public and private cooperation with other countries, institutions and corporations. This cooperation includes European and other developed countries, as well as rapidly emerging economies from all continents. Using these lessons and experiences, Denmark is trying to stimulate and inspire low-carbon growth globally.

Denmark's energy related GHG emissions only account for about 0.1% of global emissions. Consequently Danish climate and energy policies do not alter the global carbon footprint and the threats from climate change, which in the coming decades will mainly be boosted by rapidly emerging economies. Through Denmark's government-to-government cooperation with a group of leading growth economies, elements of the Danish Energy Model can affect up to 2 billion energy consumers, accounting for one third of the global GHG emissions. All of these economies do have initial significant high energy intensity than Denmark. Getting down toward the Danish levels would have a profound impact of global GHG emissions and reduce the risk of global warming.

A tangible example of this is sectorial cooperation with the Government of China on integrating large amounts of renewable energy into their power system and consequently reducing China's rapidly growing

GHG emissions. Other partner countries currently include Mexico, South Africa and Vietnam, and the list is expanding. The scope of cooperation is broad, covering energy efficiency, renewable energy and energy system development as well as climate finance.

Through the power of example, Denmark has demonstrated that energy consumption and carbon emissions can be radically improved in a short timeframe while maintaining a sound and resilient economy. An important part of the Danish effort to mitigate climate change will be stepping up international cooperation in coming years.

Public engagement and acceptance

Energy policy is well rooted in the everyday lives of Danish citizens, with significant public engagement in all aspects of the low-carbon transition. From energy efficiency measures and campaigns for households and residential buildings, ownership in renewable energy assets (roof-mounted solar panels, community owned wind farms, etc.) support for low-carbon transportation (public transportation, bicycle commuting, etc.), energy conservation and transition to low carbon options are a part of everyday life for the citizens of Denmark.

The general public support for the energy sector transition, including costs and other impacts, is an important part of the broad political consensus towards the huge changes taking place in the Danish energy sector these years, to tackle climate change and move towards more sustainable and sound economic growth.

The Danish Energy Agency's Centre for Global Cooperation supports emerging economies to combine sustainable future energy supplies with economic growth. The initiative is based on four decades of Danish experience with renewable energy and energy efficiency, transforming the energy sectors to deploy increasingly more low-carbon technologies.

Learn more on our website:
www.ens.dk/en/our-responsibilities/global-cooperation

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